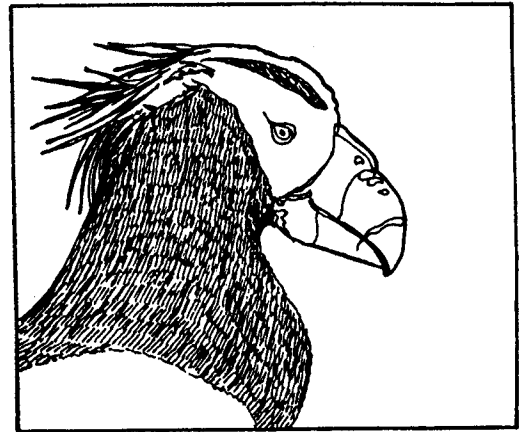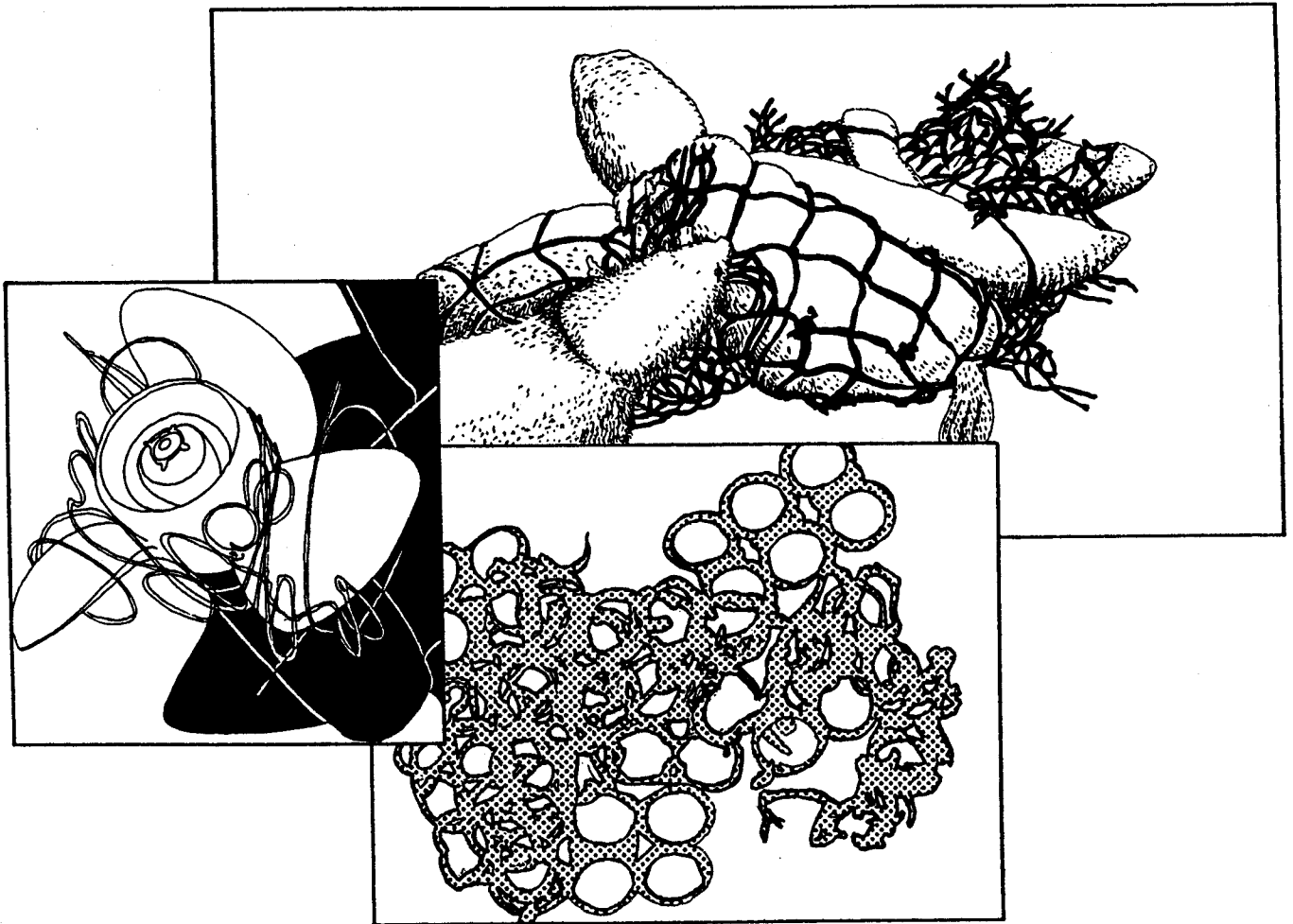# SESSION II

ENTANGLEMENT OF MARINE LIFE
AND GHOST FISHING

DISTRIBUTION OF MARINE DEBRIS AND NORTHERN
FUR SEALS IN THE EASTERN BERING SEA

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ABSTRACT

To obtain basic information about entanglement rate and mortality of the northern fur seal, *Callorhinus ursinus*, at sea, we conducted sighting surveys of fur seals and marine debris along eight transect lines in 1984 and four in 1985 and 1988 in summer near the Pribilof Islands in the eastern Bering Sea. These southeast to northwest transects were approximately 300-500 km long. We observed 710 fur seals and 7 debris items of fisheries origin in 1984, 345 seals and 17 debris items in 1985, and 343 seals and 18 debris items in 1988. In 1985, one dead male fur seal was observed entangled in a trawl net fragment weighing 40 kg. Distributions of both marine debris and fur seals were concentrated in the area along the continental slope west of the Pribilof Islands. It is considered that this co-occurrence is a result of the mutual relationship between fish resources, seals' feeding, fishing grounds of trawlers in the area, and northward-flowing current.

INTRODUCTION

Japanese trawlers began operating in the eastern Bering Sea in 1933 and other nations have begun fishing there later the U.S.S.R. in 1959, South Korea in 1968, Taiwan in 1974, Poland in 1979, and West Germany in 1980. The estimated total number of trawl-fishing vessels off Alaska increased from 5 in 1933 to 432 in 1963, and dropped to 317 in 1983 (Low et al. 1985).

At the 10th meeting of the North Pacific Fur Seal Commission (NPFSC), the survival rate of fur seals that were entangled in fishing net fragments was reported (NPFSC 1967). Since then, the United States has been actively collecting data on entanglement of fur seals (Scordino 1985). Japan-United States joint research started in 1983 (Bengtson et al. 1988; Scordino et al. 1988). The fur seal population on the Pribilof Islands has steadily declined since the 1960's, and entanglement of seals has been suggested as a partial cause (Fowler 1982).

Merrell (1980) estimated that about 1,645 metric tons of plastic material were dumped into the Bering Sea and Aleutian Islands area each year in the 1970's. Dahlberg and Day (1985) encountered 0.356 trawl debris items per 1,000 km in the central North Pacific between Kodiak Island and Hawaii, whereas Jones and Ferrero (1985) found 1.349 pieces of trawl net debris per 1,000 km off the Aleutian Islands in the North Pacific. The common pelagic distribution of fur seals and marine debris has not, however, been studied at all. If the drifting routes and local accumulations of marine debris coincide with migration routes and feeding grounds of fur seals, the probability that seals will become entangled in marine debris will increase. The greater the density of marine debris, the greater will be the number of entangled seals. To properly assess the impact of entanglement on the fur seal population, the common distribution and density of fur seals and marine debris at sea must be known.

In this study, we conducted a sighting survey for fur seals and marine debris in the eastern Bering Sea in 1984, 1985, and 1988, and obtained basic information on the pelagic distribution of fur seals and marine debris.

MATERIALS AND METHODS

We conducted sighting surveys of northern fur seals and marine debris along eight transect lines from 13 July to 8 August 1984, four from 12 to 21 July 1985, and four from 10 to 23 July 1988 in the eastern Bering Sea using RV *Shunyo Maru* (Table 1). These southeast to northwest transects were approximately 300 to 500 km long. The survey areas made up of blocks measuring 30 min of latitude by 1 degree of longitude, were 248,845 km^2 in 1984, 152,937 km^2 in 1985, and 184,066 km^2 in 1988. In 1984, both western and eastern areas of the Pribilof Islands were surveyed, and in 1985 and 1988 only the western area was surveyed (Fig. 1).

Sightings were conducted by one or two people from the pilothouse and four or five people from the flying deck (8 m above sea level) on top of the pilothouse each day from sunrise to sunset. Observers were placed on both sides of the ship and surveyed the area on only one side. Each observer engaged in sightings for 4 h and rested for 1 h. Binoculars (7 × 50) were used only to confirm the kind and number of objects observed. We recorded the number, the time, and the location of fur seals and marine debris encountered. The speed of the ship during sightings was about 8 kn in 1984 and 1985 and about 10 kn in 1988. The ship's course was not changed except to collect debris of fishing origin such as fishing net fragments, plastic packing bands, floats, and ropes. When visibility dropped to less than about 200 m, the survey was interrupted.

In 1984 and 1985 we concentrated on sighting of fisheries-related debris; however, in 1988 we recorded all floating debris including Styrofoam, nylon bags, wood, and debris of fisheries origin. Because the debris surveys differed among years, we compared only the distributions and densities of fisheries-related debris.

Table 1.--Research period, area east or west of the Pribilof Islands, distance traveled, and number of fur seals and pieces of debris of fisheries origin observed.

Period	Days	Area	Distance traveled (km)	Number of fur seals observed	Number of pieces of debris of fisheries origin observed
13-19 July 1984	7	East	1,133	71	1
25 July-8 Aug. 1984	9	West	1,855	639	6
12-21 July 1985	9	West	1,892	345	17
10-23 July 1988	9	West	2,184	343	18

RESULTS

Distribution and Kinds of Debris of Fisheries Origin

In 1984, seven pieces of debris of fisheries origin were found: two on the continental shelf northwest of the Pribilof Islands, four near the continental slope southeast of the islands, and one to the south of St. George Island (Fig. 2A). In 1985, 17 pieces of debris of fisheries origin were found 2 on the continental shelf, 12 along the continental slope, and 3 northwest of Umnak Island (Fig. 2B). In 1988, 18 pieces of debris of fisheries origin were collected 2 on the continental shelf, 9 along the continental slope, and 7 southwest of the Pribilof Islands (Fig. 2C). Generally, debris items were found along the continental slope during the 3 years.

Debris of fisheries origin collected in 1984, 1985, and 1988 included trawl nets, gillnets, string, rope, floats, and plastic packing bands. Fifteen trawl net pieces collected ranged in weight and mesh size from 15 g, 7 cm to 40 kg, 20.5 cm; two gillnet pieces were similar at 1.75 kg, 11.7 cm and 1.8 kg, 11.5 cm. Three of four packing band pieces collected weighed 6.4 kg or more (Table 2). Trawl net accounted for 71.4% (five pieces) of all debris in 1984, 41.2% (seven pieces) in 1985 and 16.7% (three pieces) in 1988 (Table 3). Trawl net constituted the major part of the collection in 1984, floats in 1988.

Entanglement of Fur Seal

We found a dead male fur seal (110 cm long and weighing 20 kg), which we estimated to be 2 years old, entangled in a net fragment about 30 nmi southwest of St. Paul Island on 19 July 1985. The net fragment was gray trawl net weighing 40 km (mesh size 20.5 cm; twine size 7.6 mm).

Distribution of Fur Seals

The sighting frequency of fur seals (number of fur seals sighted per 1 km) was calculated for each block measuring 30 min of latitude by 1 degree of longitude.
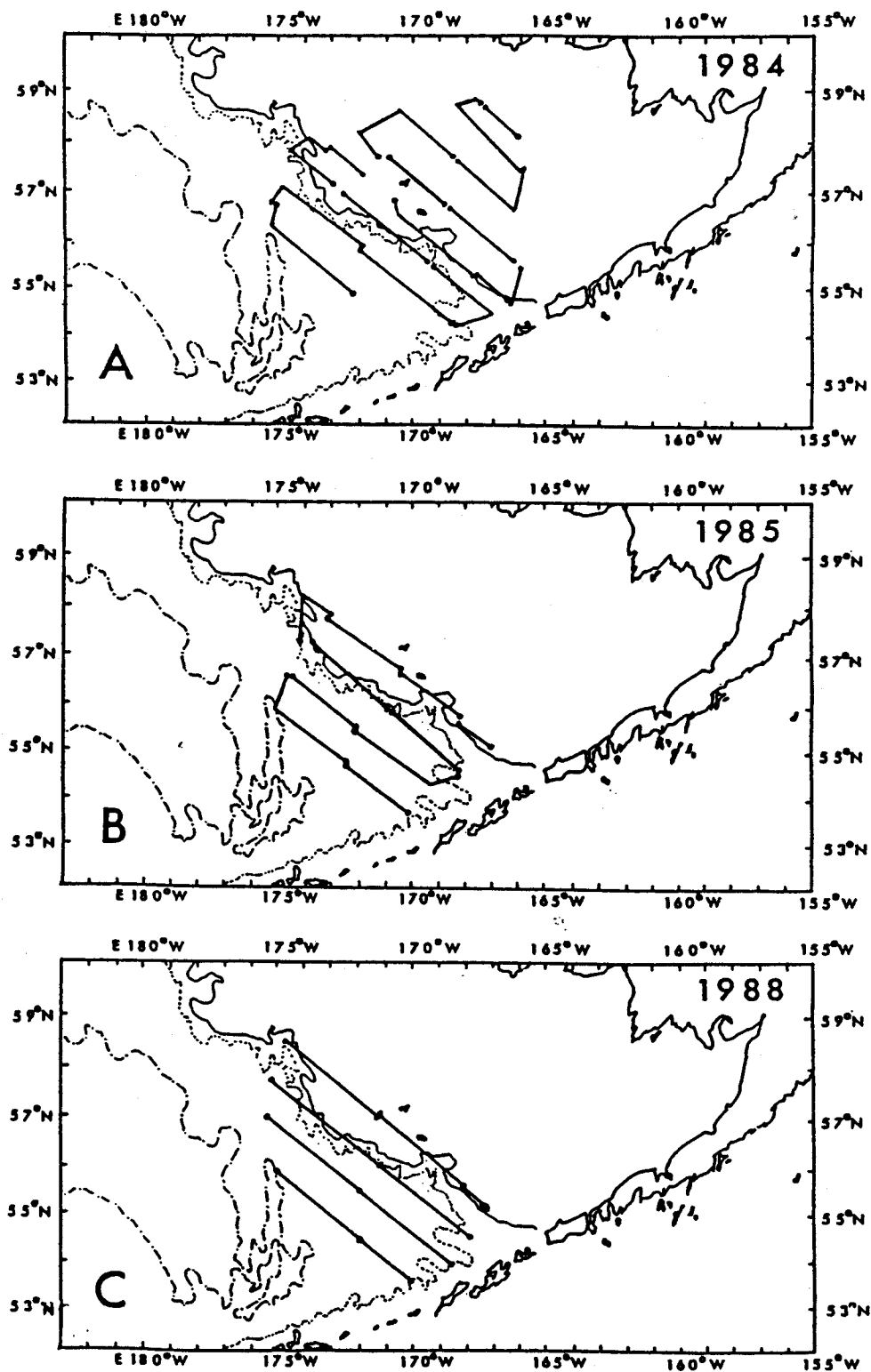
Figure 1.--Transect line surveyed in 1984 (A), 1985 (B), and 1988 (C)
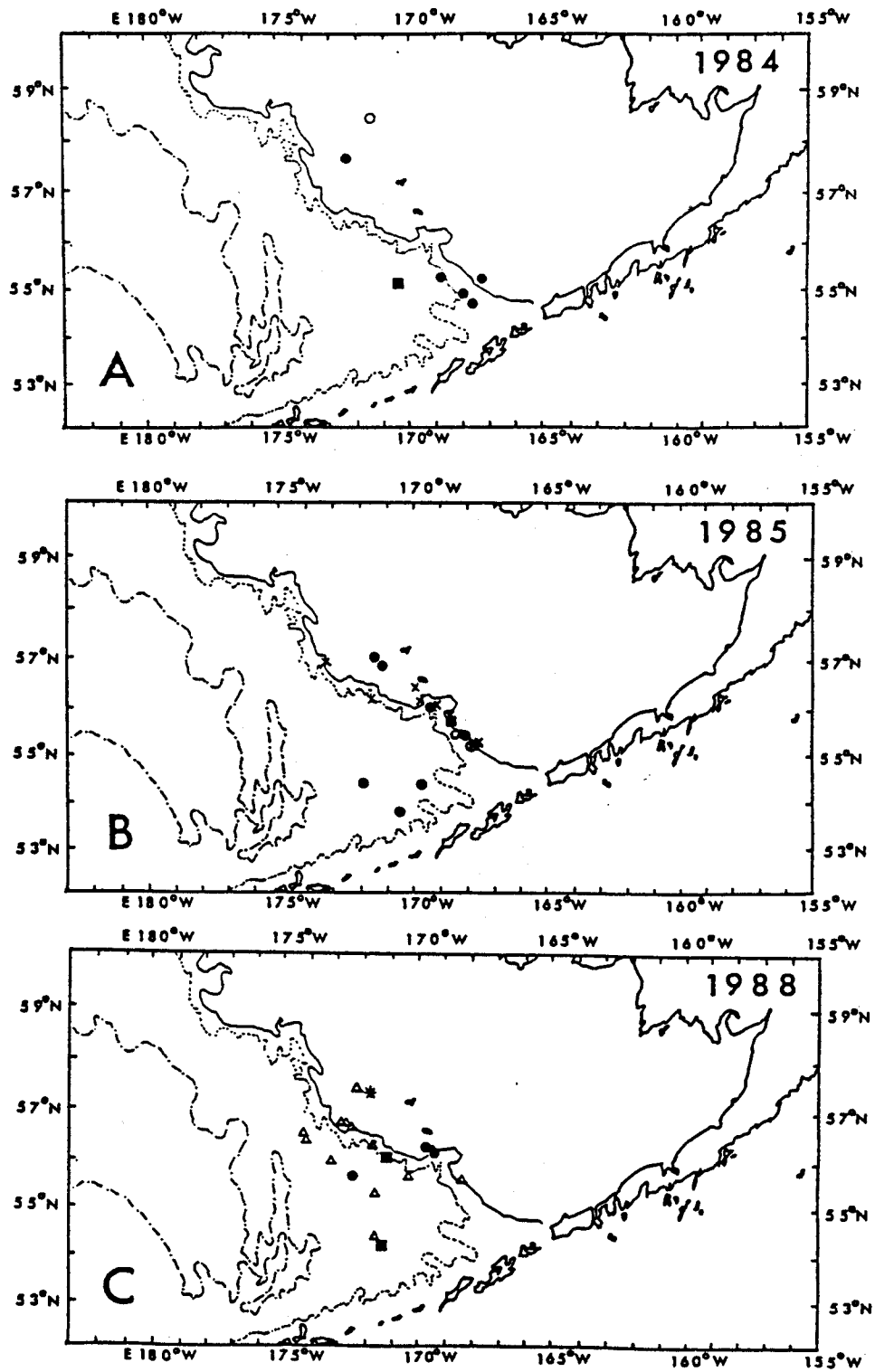(—— = 100 fathoms, --- = 1,000 fathoms, — · — = 2,000 fathoms).

Figure 2.--Location of debris of fisheries origin.
• – trawl net, o – gillnet, ✳ – unidentified net,
⊗ – string, ✕ – rope, △ – float, ▪ – plastic packing band.

Table 2.--Kinds (PP – plastic packing band), date, location, and characteristics of fisheries-related debris observed on the line transect surveys, 1984, 1985, and 1988, in the eastern Bering Sea.

No.	Kinds	Date	Latitude N	Longitude W	Color	Weight (kg)	Mesh (mm)	Twine (mm)	Length (m)
1	Gillnet	14 July 1984	58°20'	171°26'	Green	1.8	115	0.5	--
2	Trawl net	25 July 1984	55°13'	167°18'	Blue	17.6	140	4.0	--
3	Trawl net	29 July 1984	57°34'	172°20'	Blue	3.0	130	5.0	--
4	Trawl net	5 Aug. 1984	54°40'	167°37'	Green	0.015	70	3.0	--
5	Trawl net	5 Aug. 1984	54°48'	167°55'	Orange	0.35	200	3.5	--
6	Trawl net	5 Aug. 1984	55°10'	168°43'	Green	1.15	135	4.0	--
7	PP band	6 Aug. 1984	55°04'	170°22'	Yellow	9.4	--	--	--
8	Trawl net	12 July 1985	53°43'	170°21'	[a]Green	--	--	--	--
9	Trawl net	12 July 1985	54°20'	171°45'	Green	6.4	155	3.0	--
10	Trawl net	15 July 1985	54°16'	169°31'	Gray	0.52	170	3.0	--
11	Trawl net	19 July 1985	57°02'	171°20'	Orange	2.9	125	6.0×4.5	--
12	Trawl net	19 July 1985	56°57'	171°07'	Gray	40.0	205	7.6	--
							114	3.4	--
13	Trawl net	20 July 1985	56°05'	169°12'	Green	0.07	--	4.2	--
14	Trawl net	21 July 1985	55°25'	168°01'	Orange	0.03	195	2.2×4.6	--
					Black		--	3.4	--
					Green	--	--	2.0×4.4	--
15	Gillnet	21 July 1985	55°25'	168°06'	Green	1.75	117	0.5	--
16	Rope	17 July 1985	56°09'	171°33'	White	0.71	--	18.5	2
17	Rope	17 July 1985	56°59'	173°18'	Yellow	0.2	--	25.0	1.3
18	Rope	20 July 1985	56°18'	169°49'	Yellow	4.8	--	18.0	20
19	Rope	20 July 1985	56°12'	169°31'	White	1.8	--	19.8	6
20	Rope	20 July 1985	56°03'	169°06'	Yellow	8.6	--	18.0	50
21	Rope	20 July 1985	55°50'	168°32'	Yellow	2.0	--	17.4	13
22	Rope	21 July 1985	55°13'	167°27'	Yellow	0.1	--	12.4	1
23	String	21 July 1985	55°16'	167°34'	Orange	0.02	--	3.0×5.0	2
24	PP band	20 July 1985	55°50'	168°32'	White	0.01	--	--	2
25	Net	17 July 1988	57°17'	171°58'	(a)	--	--	--	--
26	Trawl net	12 July 1988	55°32'	172°25'	Gray	--	--	--	--
27	Trawl net	23 July 1988	56°06'	169°19'	Orange	0.82	129	5×3	--
28	Trawl net	23 July 1988	56°13'	169°32'	Orange	0.75	195	5×3	--
29	Float	10 July 1988	54°17'	171°41'	--	--	--	--	--
30	Float	12 July 1988	56°28'	174°18'	--	--	--	--	--
31	Float	12 July 1988	56°29'	174°18'	--	--	--	--	--
32	Float	12 July 1988	55°59'	173°13'	--	--	--	--	--
33	Float	13 July 1988	55°16'	171°40'	--	--	--	--	--
34	Float	15 July 1988	55°39'	170°21'	--	--	--	--	--
35	Float	16 July 1988	56°14'	171°42'	--	--	--	--	--
36	Float	16 July 1988	56°34'	172°28'	--	--	--	--	--
37	Float	16 July 1988	56°44'	172°47'	--	--	--	--	--
38	Float	16 July 1988	56°44'	172°48'	--	--	--	--	--
39	Float	17 July 1988	57°28'	172°21'	--	--	--	--	--
40	Float	23 July 1988	55°37'	168°18'	--	--	--	--	--
41	PP band	10 July 1988	54°09'	171°24'	Yellow	6.4	--	--	[b]Roll
42	PP band	15 July 1988	56°01'	171°11'	Yellow	6.4	--	--	[b]Roll

[a]Not collected.
[b]The roll of plastic packing band was estimated to be >100 m.

Table 3.--Kinds, number, and percent of fisheries-related debris pieces collected during line transect surveys in 1984, 1985, and 1988 in the area west of the Pribilof Islands.

Kind		1984	1985	1988	Total
Trawl net	No.	5	7	3	15
	%	(71.4)	(41.2)	(16.7)	(35.7)
Gillnet	No.	1	1	0	2
	%	(14.3)	(5.9)	(0.0)	(4.8)
Unidentified net	No.	0	0	1	1
	%	(0.0)	(0.0)	(5.6)	(2.4)
Float	No.	0	0	12	12
	%	(0.0)	(0.0)	(66.7)	(28.6)
Rope	No.	0	7	0	7
	%	(0.0)	(41.2)	(0.0)	(16.7)
String	No.	0	1	0	1
	%	(0.0)	(5.9)	(0.0)	(2.4)
Plastic packing band	No.	1	1	2	4
	%	(14.3)	(5.9)	(11.1)	(9.5)
Total	No.	7	17	18	42

In July 1984, we surveyed the area east of a line extending through St. George and St. Paul Islands. Most blocks showed fewer than 0.3 seal/km or showed no seals in this area.

In August 1984 and in July 1985 and 1988, we surveyed the area west of same line. In August 1984, more than 0.3 seal/km were seen in many blocks along the continental slope, and southwest of the islands over 0.9 seal/km were seen. No seals were found to the southeast or over the continental slope (Fig. 3A). Mean frequency of seals in all blocks west of the islands was greater than to the east, differing significantly ($t = 4.7528$, $P < 0.0001$).

In July 1985, we found fur seals mainly on the continental shelf and along the continental slope. Frequencies of over 0.6 seal/km occurred in two blocks to the northwest and southwest of St. Paul Island (Fig. 3B). Mean frequency of seals of this year was less than in August 1984, differing significantly ($t = 2.449$, $P < 0.005$).

In July 1988, we found frequencies greater than 0.3 seal/km only on the continental shelf and along the continental slope within about 200 km of the Pribilof Islands. Frequencies were greater than 0.9 seal/km in two
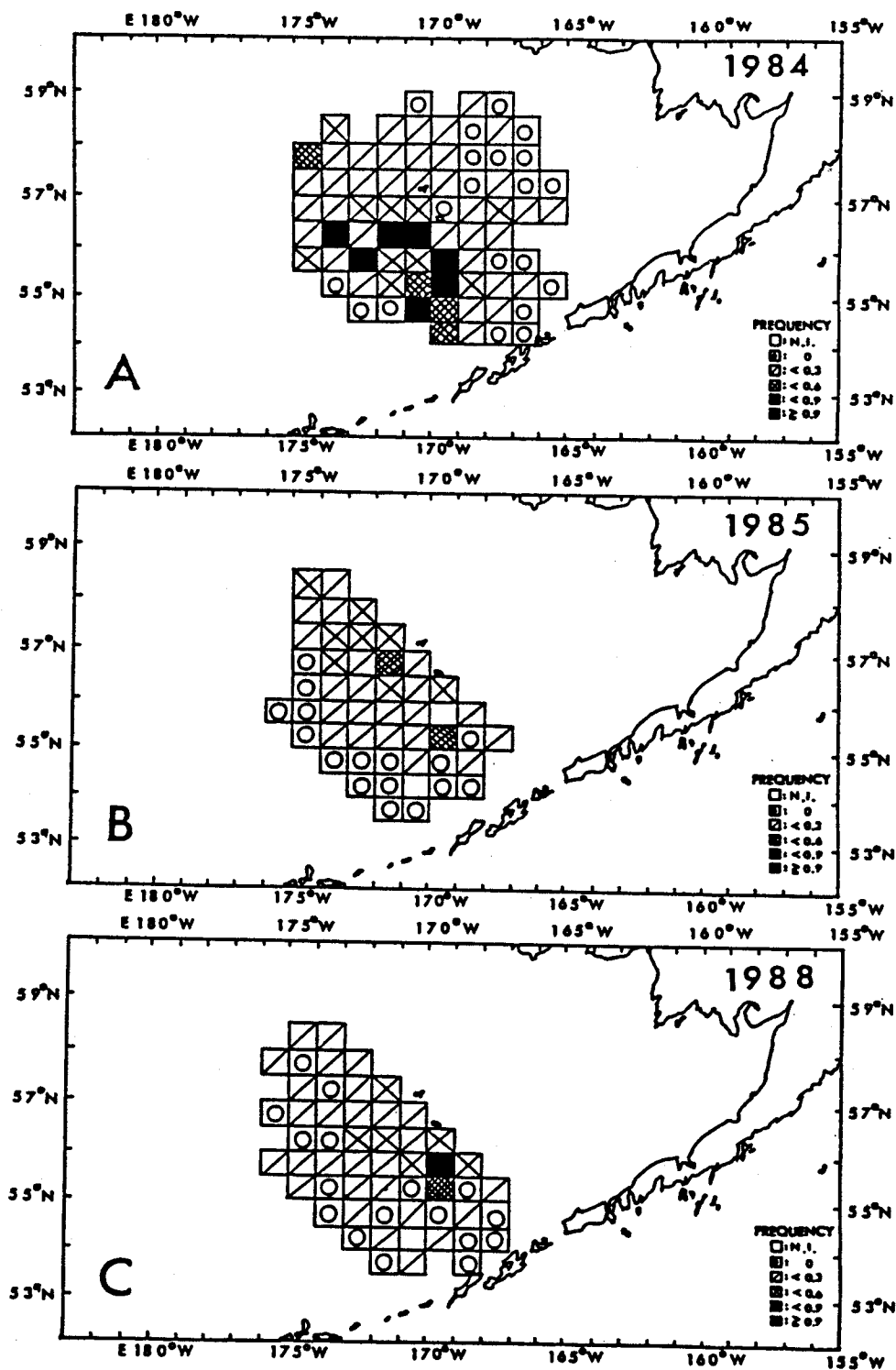
Figure 3.--Sighting frequency of fur seals per block measuring
30 min of latitude by 1 degree of longitude including transect
line. Frequency equals the number of fur seals sighted per
1 km of research distance. (NI — not investigated.)

blocks along the continental slope south of St. George Island. Generally we saw no seals near the northwestern and southeastern ends of the continental slope or along the southwestern edges (Fig. 3C). Mean frequency of seals this year was almost the same as in July 1985, not significantly different (t = 0.6499, P > 0.006).

Coincident Sightings of Fur Seals and Fisheries-Related Debris

The sighting frequencies of fur seals in coincidental areas surveyed in 1984, 1985, and 1988 were 360.4/1,000 km in 1984, 211.0/1,000 km in 1985, and 197.8/1,000 km in 1988, whereas the densities of debris (of fisheries origin only) were 2.561/1,000 km in 1984, 7.975/1,000 km in 1985, and 9.798/1,000 km in 1988 (Table 4).

DISCUSSION

Most female fur seals at St. Paul Island deliver pups in July. After a perinatal fast of 8-10 days, they go to sea to feed for 4- to 10-day periods punctuated by 1-2 days of nursing their pups. Feeding trips lengthen as pups age until they are weaned at about 120 days postpartum (Peterson 1968). York and Kozloff (1987) reported that the number of newborn pups on St. Paul Island did not change greatly between 1981 and 1986. Therefore, we believe that the greater number of fur seals sighted in 1984 was due to the later survey period (late July-early August) and consequent greater proportion of lactating females at sea then, compared with 1985 and 1988 when surveys were in early to mid-July.

In all years, we found most seals near the continental slope in the eastern Bering Sea. Echo soundings of fish biomass, which we conducted simultaneously with transect surveys, indicated that the walleye pollock, *Theragra chalcogramma*, biomass was greatest in that area (Harada et al. 1985). Kajimura (1984) reported that fur seals in the Bering Sea ate mostly capelin, *Mallotus villosus*, and walleye pollock in July and August.

Table 4.--Sighting frequency of fur seals and fisheries-related debris (fishing nets, rope, string, plastic bands, floats) observed on the line transect surveys in 1984, 1985, and 1988 west of the Pribilof Islands.

Period	Research distance (km)	Seals No.	Debris No.	Frequency per 1,000 km Seals[a]	Debris[b]
25 July-8 Aug. 1984	1,562	563	4	360.4	2.561
12-21 July 1985	1,630	344	13	211.0	7.975
10-23 July 1988	1,633	323	18	197.8	9.798

[a]Number of seals divided by research distance.
[b]Number of debris items divided by research distance.

Trawl-net fisheries for those species also operate primarily along the continental shelf and the continental slope in the eastern Bering Sea (Mito 1986), also suggesting that the greatest fish biomass is concentrated there. We believe that our observations showing most marine debris and most fur seals concentrated in the area from the continental shelf to the continental slope west of the Pribilof Islands are related to the concentration of prey resources and marine debris (e.g., fishing net, plastic packing bands) in that area and to the northward currents along the continental slope (Favorite et al. 1976) which act to concentrate debris there.

As fur seals migrate in winter from the Pribilof Islands to as far south as Mexico in the eastern Pacific (lat. 32°N) (Kajimura and Loughlin 1988), we feel that it is important to conduct surveys in waters off British Columbia, Washington, Oregon, and California in the future to ascertain the distribution and abundance of marine debris and fur seals there.

ACKNOWLEDGMENT

REFERENCES

Bengtson, J. L., C. W. Fowler, H. Kajimura, R. L. Merrick, K. Yoshida, and S. Nomura.
    1988. Fur seal entanglement studies; juvenile males and newly weaned pups, St. Paul Island, Alaska. *In* P. Kozloff and H. Kajimura (editors), Fur seal investigations, 1985, p. 34-57. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-146.

Dahlberg, M. L., and R. H. Day.
    1985. Observations of man-made objects on the surface of the North Pacific Ocean. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 198-212. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Favorite, F., A. J. Dodimead, and K. Nasu.
    1976. Oceanography of the subarctic Pacific region, 1960-71. Int. North Pac. Fish. Comm. Bull. 33:1-187.

Fowler, C. W.
    1982. Interactions of northern fur seals and commercial fisheries. Trans. N. Am. Wildl. Nat. Resour. Conf. 47:278-292.

Harada, Y., N. Nagai, S. Toishi, K. Yoshida and N. Baba.
    1985. Estimation of the pollock biomass in the sea around the
    Pribilof Islands in the Bering Sea from mid-July to mid-August,
    1984. Background paper submitted to the 28th meeting of the
    Standing Scientific Committee of the North Pacific Fur Seal
    Commission, 18 p.

Jones, L., and R. C. Ferrero.
    1985. Observations of net debris and associated entanglements in the
    North Pacific Ocean and Bering Sea, 1978-84. *In* R. S. Shomura and
    H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and
    Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p.
    183-196. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-
    SWFC-54.

Kajimura, H.
    1984. Opportunistic feeding of the northern fur seals, *Callorhinus
    ursinus*, in the eastern North Pacific Ocean and Bering Sea. U.S.
    Dep. Commer., NOAA Tech. Rep. NMFS-SSRF-779:1-49.

Kajimura, H., and T. R. Loughlin.
    1988. Marine mammals in the oceanic food web of the eastern subarctic
    Pacific. Bull. Ocean Res. Inst., Univ. Tokyo 26:187-223.

Low, L.-L., R. E. Nelson, Jr., and R. E. Narita.
    1985. Net loss from trawl fisheries off Alaska. *In* R. S. Shomura and
    H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and
    Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p.
    130-153. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-
    SWFC-54.

Merrell, T. R.
    1980. Accumulation of plastic litter on beaches of Amchitka Island,
    Alaska. Mar. Environ. Res. 3:171-184.

Mito, K.
    1986. Outline of the Japanese groundfish fishery in the Bering Sea in
    1985 January-December and 1986 January-July. Document submitted to
    the Annual Meeting of the International North Pacific Fisheries
    Commission, Anchorage, Alaska, October 1986. Fisheries Agency of
    Japan, Tokyo, 100 Japan, 5 p.

North Pacific Fur Seal Commission.
    1967. Report of the Standing Scientific Committee. *In* Proceedings of
    the Tenth Annual Meeting, North Pacific Fur Seal Commission. Issued
    from the Headquarters of the Commission, Washington D.C., 48 p.

Peterson, R. S.
    1968. Social behavior in pinnipeds with particular reference to the
    northern fur seal. *In* Harrison et al. (editors), The behavior and
    physiology of pinnipeds, p. 3-53. Appleton-Century-Crofts, N.Y.,
    409 p.

Scordino, J.
　　1985.　Studies on fur seal entanglement, 1981-84, St. Paul Island,
　　Alaska.　*In* R. S. Shomura and H. O. Yoshida (editors), Proceedings
　　of the Workshop on the Fate and Impact of Marine Debris, 26-29
　　November 1984, Honolulu, Hawaii, p. 278-290.　U.S. Dep. Commer.,
　　NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Scordino, J., H. Kajimura, N. Baba, and A. Furuta.
　　1988.　Fur seal entanglement studies in 1984, St. Paul Island, Alaska.
　　In P. Kozloff and H. Kajimura (editors), Fur seal investigations,
　　1985, p. 70-78.　U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-146.

York, A. E., and P. Kozloff.
　　1987.　On the estimation of numbers of northern fur seal, *Callorhinus
　　ursinus*, pups born on St. Paul Island, 1980-86.　Fish. Bull., U.S.
　　85:367-375.

POTENTIAL IMPACT OF ENTANGLEMENT IN MARINE DEBRIS ON THE POPULATION DYNAMICS OF THE NORTHERN FUR SEAL, *CALLORHINUS URSINUS*

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ABSTRACT

A model of the population dynamics of the Pribilof Island population of the northern fur seal, *Callorhinus ursinus*, was developed using field estimates of age- and sex-specific mortality and reproductive rates. In the model, mortality rates of pups and juveniles are density dependent, while rates for older seals are constants for each age and by sex. Model-predicted pup production is compared to pup counts made in the field.

If initialized at 1912 numbers, the model population increases at the rate observed between 1912 and 1940, then oscillates around the population level of the 1940's and 1950's, thought to be the carrying capacity of the Pribilof Islands. When the female harvest (including pelagic collections) of 1956-74 is added to the simulation at the annually specified rates, the predicted pup production decreases until 1965, but recovers to preharvest levels by 1975.

Entanglement rate and resulting mortality are assumed to be proportional to the rate of entanglement of subadult males in the harvest, specified by year. When both female harvest and mortality resulting from entanglement in plastic debris are added to the simulation, the model population declines at observed rates, suggesting that entanglement mortality can account for the recent decline in the fur seal population. The model indicates that the population will continue to decline at 1% per year if mortality remains at current levels. This rate of decline is slower than the 4-8% decrease per year of the 1970's because of higher pup and juvenile survival rates at lower population density. The model indicates that a reduction in entanglement mortality rates by 20% would be enough to stop the current population decline and maintain the population at current levels.

INTRODUCTION

In the early 1900's, the population of the northern fur seal, *Callorhinus ursinus*, breeding on the Pribilof Islands in the Bering Sea had been reduced by harvesting to about 300,000 total individuals and fewer than 100,000 pups born per year. A ban on harvesting in 1911 by international agreement allowed the population to recover, such that a population level estimated at about 2 million total individuals was reached by the 1940's and continued through the 1950's. (See reviews by York and Hartley 1981; Lander and Kajimura 1982; Scheffer et al. 1984; Fowler 1985a.) In 1956, harvest of females was begun in an effort to reduce the population size to a level at which the then-predicted maximum sustainable yield in pup production could be obtained. The harvest of females was continued until 1968, and pelagic collections of females for research purposes were made between 1958 and 1974 (York and Hartley 1981). When the female harvest was ended, it was expected that the population would increase and return to the 1950's population level. However, the population has continued to decline at 4-8% per year since the late 1970's (Briggs and Fowler 1984). Evidence indicates that this decline may be the result of lethal entanglement in fishing debris and plastic packing bands (Fowler 1985a, 1985b).

In order to evaluate quantitatively the effect of the female harvest and entanglement on the Pribilof Island fur seals, we have developed a population dynamics model and have compared resulting predicted pup production against estimates made in the field. The population model consists of annual age classes of males and females with mortality and reproductive rates which are dependent on age and sex. Mortality of pups on land and of juveniles during their first 20 months at sea is density dependent, while mortality rates of older seals and pregnancy rates of females are density-independent, age-specific constants using best available estimates. Harvest mortality is considered separate from natural mortality and, when applicable, occurs only during the summer harvest season. Entanglement mortality rates are added to natural mortality when simulating the population dynamics of the last two decades.

MODEL ASSUMPTIONS

The age-specific pregnancy rates calculated by York (1979), using data from the pelagic collections conducted by the United States and Canadian Governments between 1958 and 1974, are assumed as birth rates (Table 1 and Fig. 1). Therefore, reproductive rates in the model are dependent solely on the number of adult females, assuming that enough adult males are present to impregnate those females at all population densities. The sex ratio at birth is assumed 1:1.

Natural mortality of seals age 2 or more years is assumed to be constant by age class and sex. In the model, natural mortality does not include mortality due to commercial harvest (or pelagic collection for research purposes) or recent mortality believed to be due to entanglement in fishing gear. Natural mortality rate estimates by age and sex are available from several sources (Chapman 1964; Lander 1979, 1980a, 1981; Eberhardt 1981; Smith and Polacheck 1984). Those of Lander (1980a, 1981;

Table 1.--Pregnancy rates (York 1979), age-specific natural
mortality rates (Lander 1980a, 1981), and harvest rates on
immature males (Lander 1980a) used in the population dynamics
model. (Asterisks indicate rates which are density dependent
and therefore not constants.)

Age	Percent of females pregnant	Natural survival rate (per year)		Male harvest rate (per year)
		Female	Male	
1	0	*	*	0
2	0	0.840	0.78	0.028
3	0	0.920	0.77	0.403
4	4	0.940	0.76	0.573
5	37	0.940	0.74	0.147
6	70	0.945	0.72	0
7	80	0.950	0.72	0
8	85	0.950	0.72	0
9	87	0.938	0.70	0
10	88	0.924	0.65	0
11	88	0.906	0.63	0
12	88	0.884	0.60	0
13	87	0.858	0.55	0
14	84	0.876	0.50	0
15	81	0.789	0.43	0
16	77	0.743	0.30	0
17	71	0.692	0.20	0
18	63	0.630	0.10	0
19	56	0.564	0	0
20	47	0.490		
21	37	0.411		
22	26	0.330		
23	11	0.300		
24	0	0.250		
25	0	0.200		
26	0	0.150		
27	0	0.100		
28	0	0.050		
29	0	0		

Table 1 and Fig. 2) are assumed in the present model, after correction for
subadult male harvest rate was made.

The use of constant mortality rates assumes that mortality is inde-
pendent of population density. While there is no evidence to date that
mortality of older fur seals is density dependent, there is evidence of
density dependence for the mortality of pups on land and for juveniles <2
years old (Fowler 1984, 1985a; Smith and Polacheck 1984). Thus, density-
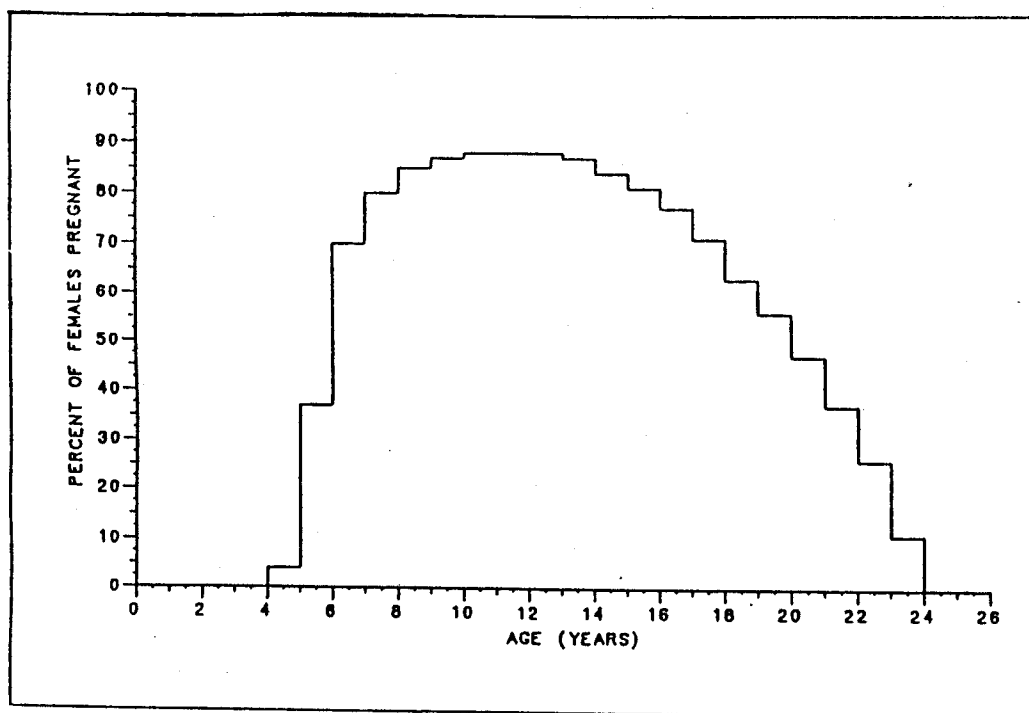dependent relationships for these age groups are included in the model.

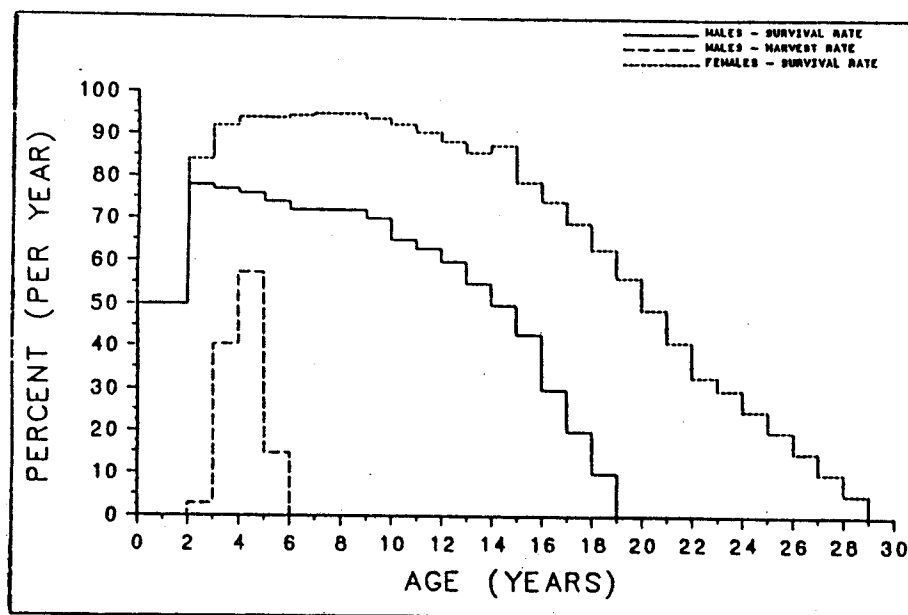Figure 1.--Pregnancy rate as a function of age.

Figure 2.--Natural survival and harvest rates as functions of age and sex (after Lander 1980a, 1981).

The mortality of pups on land appears to increase with increasing number of pups counted on the rookeries (Lander 1979; Swartzman 1984). In the model, natural mortality rate of pups on land is a function of the number of pups born, assuming the functional relationship drawn by Swartzman (1984) between pups born on St. Paul Island and their estimated mortality (line SL in Fig. 3). Pups born on St. Paul are assumed to represent 80% of the total for the two islands, St. Paul and St. George (Briggs and Fowler 1984; Smith and Polacheck 1984). Pups are assumed to remain on land for 128 days (based on data of Gentry and Holt 1986) and on-land mortality is applied over that time period. Male and female pups suffer the same rate of mortality while on land.

Survival during the first 20 months at sea also appears to be related to the number of pups born (Chapman 1961; Lander 1979; Eberhardt 1981; Fowler 1985a, 1985b). Using data for the 1950 to 1970 year classes (Fig. 4, line PA), Lander (1979) found that survival of males during their first 20 months at sea is linearly related to pup survival on land. As pointed out by Fowler (1985b), when data for the years after 1970 are included, the relationship no longer holds. Fowler presented evidence that this difference in juvenile mortality is related to the increase of entanglement in fishing debris and other plastic materials, which he believed to become significant after 1965. Therefore, a linear regression for the data of 1950-65, excluding 1956, is used in the present model, as suggested by Fowler (1985b, line PB in Fig. 4).

Survival rates of female juveniles appear to be higher than those of males of the same age (Chapman 1961, 1964; York 1987). However, the magnitude and density dependence of female juvenile survival is unknown. Using a variety of techniques, Chapman (1961, 1964) estimated the ratio of female to male survival to age 3. From a simple population model using weighted-average pregnancy rates and mortality rates of females older than 3 years, Chapman (1961) calculated that this ratio should be about 2.0. In a similar analysis, Chapman (1964) calculated a ratio of 1.72 using 1920's population estimates and 1.27 using 1950's data. Based on tagging returns, Chapman (1964) estimated the ratio of female to male survival to age 3 for 10 year classes (1951-60), finding an average value of 1.64. However, he pointed out that these estimates are probably biased such that the ratio should be higher. Two of the ten tagging estimates were about 1.27, and the other eight (later) estimates averaged 1.74. Thus, two values for the ratio of female to male survival to age 3 were tried in the present model, 1.27 and 1.74. Since mortality of pups on land is assumed the same for both sexes and mortality from age 2 to 3 is 1.077 times as high for females as males (Table 1), the ratio of female to male survival during the first 20 months at sea is assumed 1.18 or 1.62.

Because the number of males over the age of 2 years has no influence on female survival rate, reproductive rate, or future population size in the model, the mortality rate of males older than 2 influences only the number of males in the population. Thus, harvest rate of subadult males is assumed to be zero in all simulations reported here, except as indicated where the 1970's harvest rates in Table 1 and Figure 3 are used.
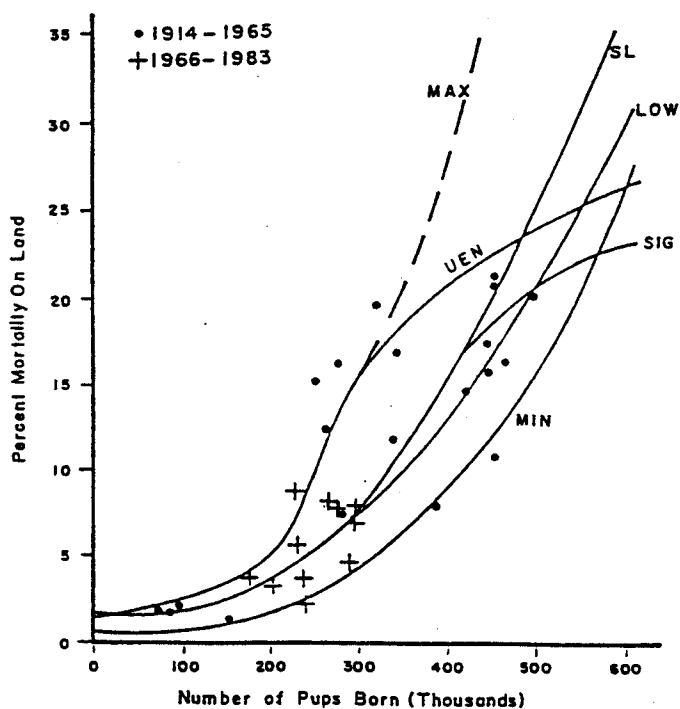
Figure 3.--Alternate density-dependent pup mortality curves.
Data are from Lander (1980b); SL is the curve drawn by Swartzman
(1984) through the data; MAX and MIN are the maximum and minimum
curves tested here; UEN is a sigmoid alternative to MAX; SIG is
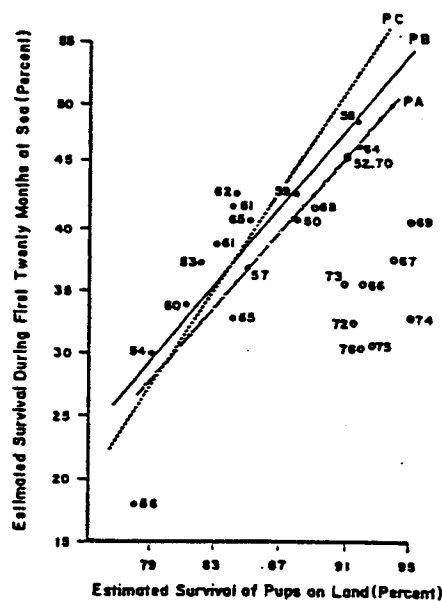a sigmoid alternative to SL; and LOW is a lower version of SL.

Figure 4.--Alternate linear regressions of juvenile mortality
rate as a function of pup survival. PA is from Lander (1979),
regressed on the data for 1950-70; PC is the same, but for 1950-
65 (before significant entanglement is thought to have occurred);
and PB is for 1950-65, excluding 1956.

Harvest rate of females is assumed to be zero, except when specifi-
cally simulating the years 1956 to 1974. For those years, the numbers of
females by age harvested or collected pelagically (as reported in York and
Hartley 1981) are subtracted from the model population at the time of
harvest during the specific year. As assumed by York and Hartley, the age
distribution of females in the harvest where age was not determined is
assumed to be the same as that for harvested females of known age. The age
distribution of females grouped as older than a specified age (e.g., 10
years) is assumed to be equivalent to the age distribution in the model
population for that year.

Entanglement mortality rates are the least known of the model param-
eters which must be estimated. Fowler (1985a, 1985b) has shown that, while
there is a linear relationship between male juvenile survival the first 20
months at sea and pup survival on land using data up to 1965, following
1965 the model no longer fits the observations. The discrepancy between
the model and observed juvenile mortality for the years after 1965 is
linearly correlated with the rate of entanglement observed in the subadult
male harvest. This suggests the discrepancy is due to entanglement
mortality. The discrepancy (as percent mortality) is added to natural
mortality of juveniles up to 2 years of age in the model when entanglement
is added to the simulation. Because the average percent entanglement in
the harvest has stabilized at 0.4% since the late 1970's, the corresponding
discrepancy of 15% mortality is assumed for both male and female juveniles
as a starting point in model simulations. The discrepancy has ranged from
7 to 25% since 1966 as rates of entanglement have varied (Fowler 1985b).

Mortality rate for entangled males between 2 and 3 years of age was
estimated by Fowler (1985b) from the relative frequency of entangled males
in the 2- and 3-year-old age classes in the harvest. His estimate is that
5.5% of 2- to 3-year-old males become entangled each year and that 90.3% of
entangled males die. Thus, 5% mortality due to entanglement is used in
model simulations for male seals between 2 and 3 years of age. Females of
this age are assumed to suffer the same or higher rates of entanglement
mortality, due to their smaller size (see Discussion).

Entanglement mortality rates of older seals are not available. Fowler
(1985b) suggests that entanglement mortality of seals over 3 years of age
is assumed to be between 0 and 5% per year. Different values were tried in
various simulations. Both males and females are assumed to suffer the same
entanglement mortality once past the age of 3.

For all simulations, the populations were initialized at 1 January
sizes and ages. A daily time step was used. Mortalities and births were
calculated on appropriate dates in the yearly cycle.

RESULTS

Simulation of the Population at Carrying Capacity

Assuming the above-described pregnancy rates, constant natural mortal-
ity rates for seals over age 2, no harvest on either males or females, and

no entanglement mortality, the density-dependent pup mortality relationship SL in Figure 3, and the male juvenile survival relationship PB in Figure 4, population equilibria were found for each of the two assumed values of the ratio of female to male survival up to the age of 3, 1.27 and 1.74. Assuming this ratio is 1.27, the population reaches 1.73 million total individuals (censused on 1 January), 1.15 million total females, and 442,000 pups born per year. If the female to male survival ratio is assumed to be 1.74, the total population reaches 1.95 million seals, 1.39 million females, and 540,000 pups born each year.

In the 1940's and 1950's, the fur seal population on the Pribilofs was relatively stable, with 525,000-576,000 pups born each year in the 1950's. This population is thought to have been at carrying capacity for the Pribilof Islands (Fowler 1985a). The model population, assuming a female-to-male survival ratio to age 3 of 1.74, is consistent with observations, while the lower ratio of 1.27 causes the model population to fall short of the observed levels.

If the model is initialized at 15% of the equilibrium population size, a level where pup production matches that of 1912, the model population and number of pups born increase at the same rate as observed pup counts in the 1910's and 1920's, 7.4% per year (Fig. 5). The model population overshoots the equilibrium size in the early 1940's, and afterwards oscillates around the equilibrium of 540,000 pups born per year, with the oscillation damping out over time. The agreement between the model and the observed rate of increase in the 1910's and 1920's suggests that the assumed pregnancy and mortality rates are realistic. Furthermore, a ratio of female to male survival to age 3 on the order of 1.74 is consistent with available data. This ratio was suggested by Chapman's results (1961, 1964), even though he and others have been more comfortable with a much lower ratio. When this same simulation is run with the female-to-male juvenile mortality ratio at 1.27, the projected population increase from the 1912 level is less than the observed rate of increase (Fig. 6).

To determine how sensitive the simulated carrying capacity population is to the various pregnancy and mortality rates assumed, these rates were varied individually within the range of possibilities observed to determine resulting population size. Alternate pregnancy rates by age (up to age 11) were taken from Chapman (1964) and from estimates reported in Smith and Polacheck (1984, table 11), which were based on Japanese collections of females between 1958 and 1960. The Japanese estimates represent the highest reported values for pregnancy rates of younger females. These high rates increase pup production to 583,000 per year (+8%) and decrease the total number of females by 9% (Table 2). Chapman's pregnancy rate estimates increase pup production by only 2% and have almost no effect on the total number of females in the population.

The density-dependent relationship between pups born and pup mortality on land is associated with a large amount of variation, and a number of alternate curves through the observed data were tried (Fig. 3). The resulting carrying capacity population varies from 23% higher to 25% lower than the model result using the standard assumptions (Table 2). Thus, the model is fairly sensitive to this assumed relationship.
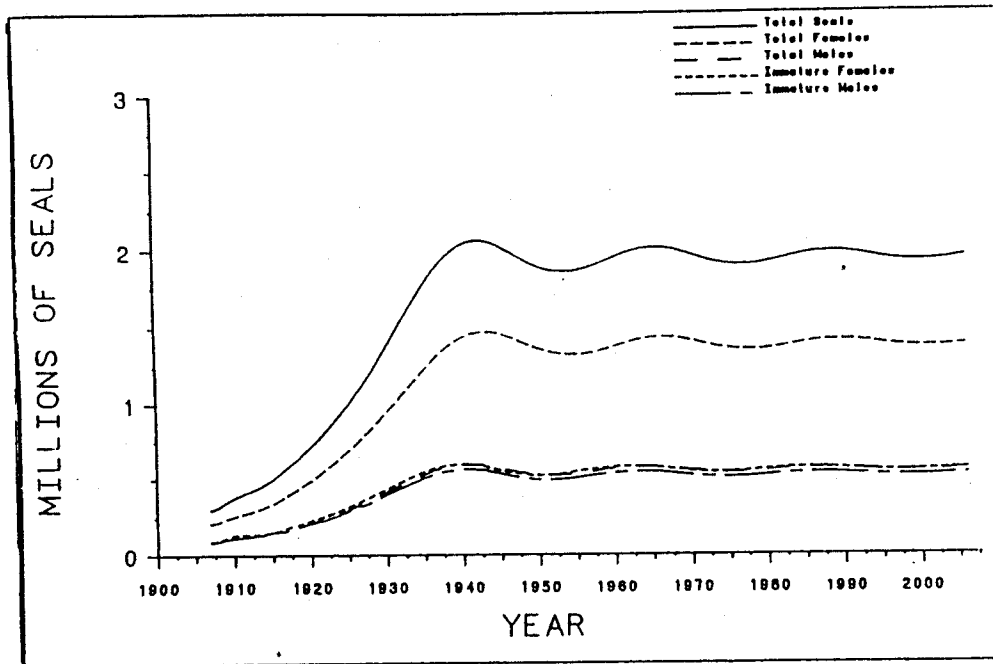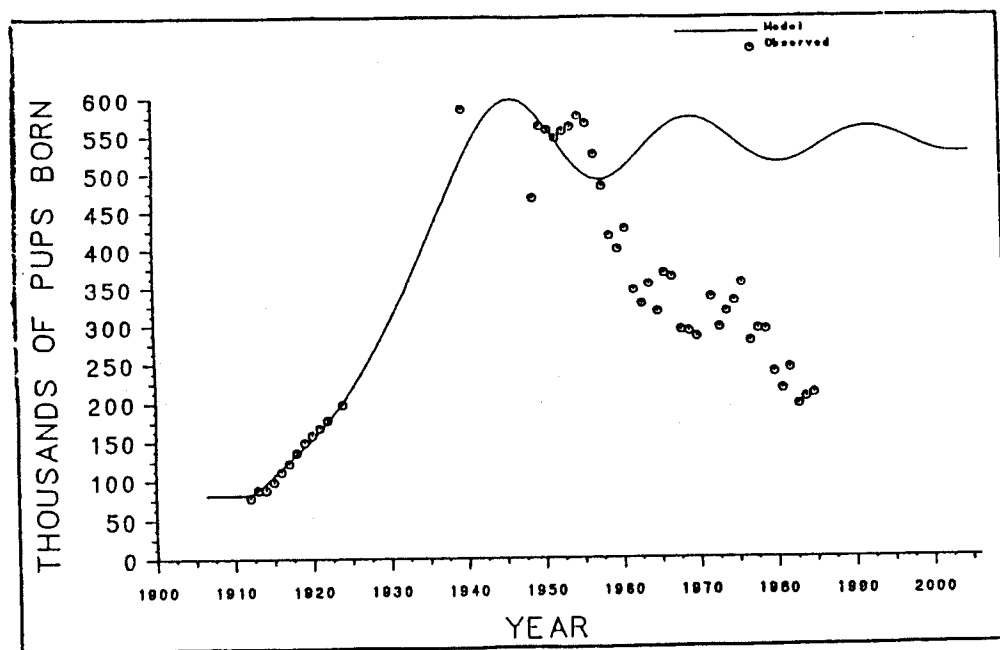
Figure 5a.

Figure 5b.

Figure 5.--Simulated increase in (a) population level (on 1 January)
and (b) number of pups born each year from the depleted population
of 1912 to carrying capacity reached by the 1940's. The ratio of
female to male survival to age 3 is 1.74. Harvest and entanglement-
induced mortality are assumed zero in the simulation.

Table 2.--Resulting equilibrium population levels (on 1 January)
and number of pups born each year (in millions of seals) when
reproductive rates or mortality rates of certain age groups are
varied (see text for specific rate variations) from the standard
run producing the best fit to the 1950's carrying capacity popu-
lation (pregnancy as in Table 1; pup mortality as curve SL in
Figure 3; male juvenile survival as line PB in Figure 4; ratio of
female to male survival to age 3 - 1.74; no harvest; and mortality
over age 2 as in Table 1).

Reproductive or mortality rate(s) varied	Total seals	Total females	Pups born
Standard run (equilibrium of Fig. 5)	1.95	1.39	0.540
Pregnancy rates:			
As in Chapman (1964)	1.93	1.38	0.553
As in Japanese collections, 1958-60	1.79	1.27	0.583
Pup mortality curve (from Fig. 3):			
MIN	2.37	1.71	0.647
LOW	2.23	1.59	0.622
SIG	2.20	1.57	0.611
UEN	1.62	1.16	0.450
MAX	1.46	1.04	0.407
Male juvenile survival line (from Fig. 4):			
PA	1.92	1.37	0.533
PC	1.91	1.36	0.527
Ratio of female to male survival to age 3:			
2.0	2.00	1.46	0.570
1.64	1.92	1.36	0.529
1.37	1.81	1.23	0.473
1.27	1.73	1.15	0.442
1.08	1.54	0.99	0.376
Subadult male harvest rates:			
As in Table 1	1.92	1.39	0.540
Adult female mortality rates:			
As in Chapman (1964)	1.96	1.39	0.509
As in Smith and Polacheck (1984)	1.90	1.31	0.454

Male juvenile survival as a function of pup survival on land was
varied to be as line PA in Figure 4, i.e., the relationship in Lander
(1979), and as line PC in Figure 4, i.e., including all data from 1950 to
1965 in the regression. The resulting population size differed from the
standard run using line PB (Fig. 4) by at most 2%. Thus, the results are
insensitive to this amount of variation of the relationship.

The ratio of female to male survival to age 3 has been estimated by Chapman (1961, 1964) as between 1.25 and 2.0. The resulting model population sizes range from 18% less than to 5% greater than the standard population model run where the ratio is 1.74 (Table 2). Thus, the model is fairly sensitive to the assumed ratio within the range of estimates which have been made. If the ratio is assumed to be 1.0, the population reaches an equilibrium 30% lower than the standard model equilibrium (Table 2), a level well below the 1950's population size.

As mortality of males over the age of 2 has no influence on female or pup population size in the model, the model population is insensitive to variation in subadult male harvest rates or variation in natural mortality of males over the age of 2. A subadult male harvest rate equivalent to that in the 1970's (Lander 1980a) reduces the total male population by 5% (Table 2).

Mortality rates of females over the age of 3 as given by Chapman (1964) result in the same number of total females in the population as the standard model assumptions (Lander 1981), but the age distribution is such that only 509,000 pups are born per year (-6%, Table 2). The lower estimated survival rates of Smith and Polacheck (1984) reduce the female population by 6% and pup production at equilibrium by 16%. However, the estimates of Lander (1981) are based on considerably more data than the other two sets of estimates, and the error of the standard model run associated with error in adult female mortality rates is probably somewhat less than these results.

Simulation of the Pribilof Population Decline Since 1958

When the female harvest and pelagic collection of 1956-74 is removed from the simulated carrying capacity population during those years, the predicted number of pups born decreases until 1965 and subsequently recovers to the preharvest level by 1975 (Fig. 7). While the female harvest may account for some of the decline after 1958, it is clearly a minor perturbation from which the population should have rapidly recovered, assuming the carrying capacity remained unchanged from the 1950's level.

The population decline after the female harvest ceased has been a subject of much discussion in recent years, with the prevailing opinion being that lethal entanglement is the most likely causative factor (Fowler 1985a, 1985b). Assuming that entanglement became significant in 1966 (as suggested by Fowler), that an additional 15% of males and females die from entanglement by age 2, and that 5% mortality of all seals age 2 and older is due to entanglement, the resulting pup production is as in Figure 8. Under these assumptions, the model population does not decline as fast as the observed pup production indicates it should. This suggests that entanglement mortality may have been significant before 1966, or that there is some other cause of the additional mortality after 1958. If the same assumed mortality rates are initiated in 1960, the model decline fits the observed more closely (Fig. 9).
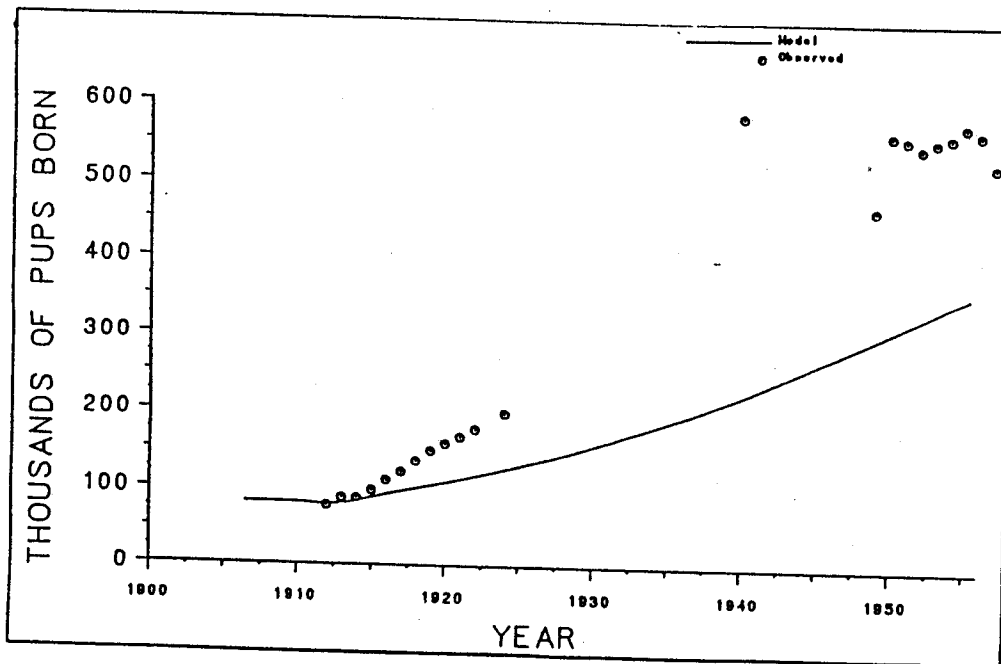
Figure 6.--Number of pups born in model population assuming the same rates as in Figure 5, except the ratio of female to male survival to age 3 is assumed to be 1.27.
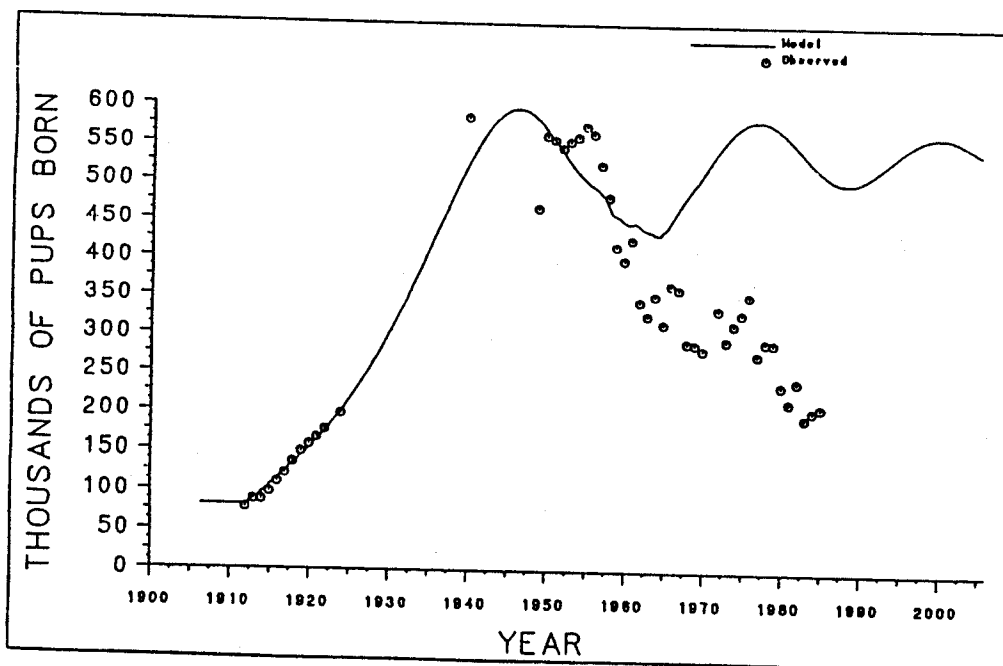

Figure 7.--Number of pups born to modeled and observed populations over time, including simulation of female harvest between 1958 and 1974 but assuming no mortality due to entanglement.
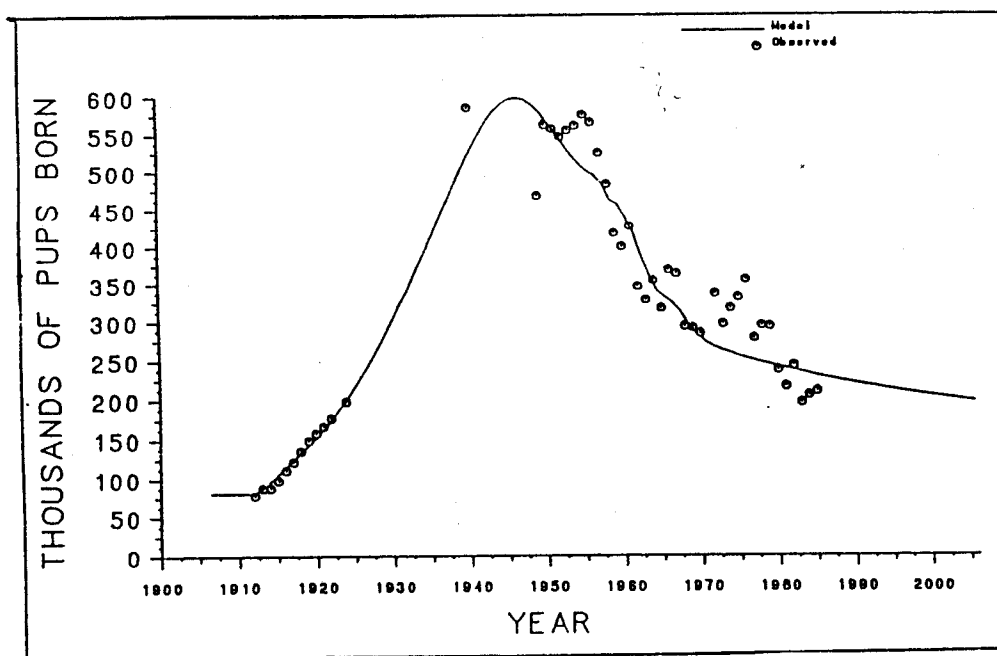
Figure 8.--Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-79) and constant entanglement mortality of 15% before and 5% after 2 years of age beginning in 1966.
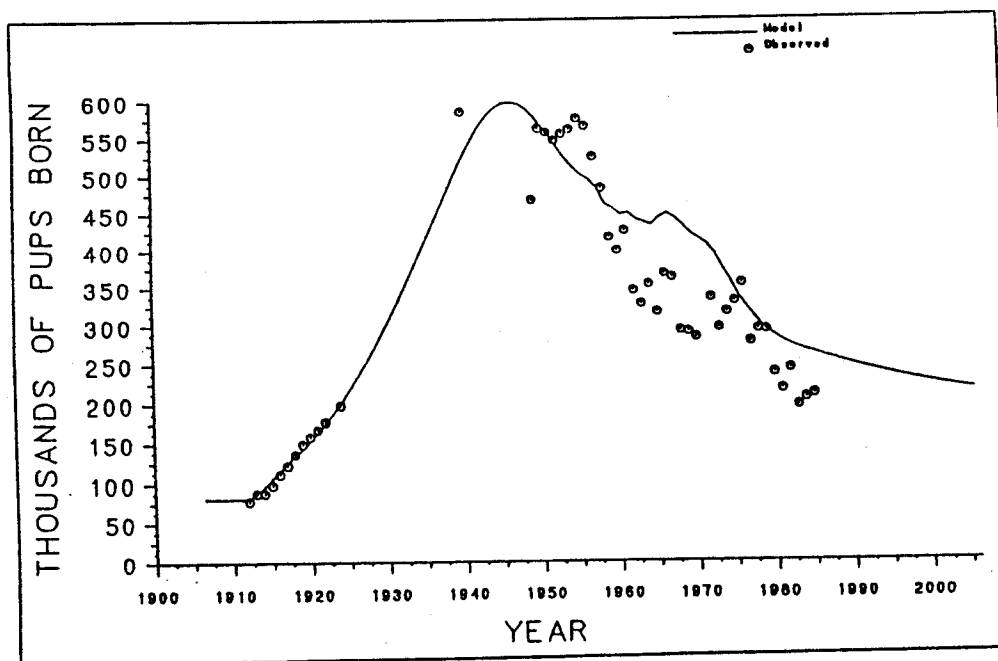

Figure 9.--Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-79) and constant entanglement mortality of 15% before and 5% after 2 years of age beginning in 1960.

In the model runs shown in Figures 8 and 9, all seals over age 2 are assumed to suffer 5% mortality per year due to entanglement. If seals over age 3 are assumed to suffer insignificant (zero) mortality due to entanglement, as suggested by Fowler (1985b), the model population declines to only 1.06 million total females with 401,000 pups born per year, a level much higher than observations for the last two decades (Fig. 10). Thus, adult females must be suffering mortality over and above Lander's (1981) estimated rates, whether due to entanglement or some other cause.

The rate of entanglement in the subadult male harvest was not constant between 1967 (the first year of observation) and the present. Before 1970, entanglement rate was below 0.4%. From 1973 to 1975 it increased to about 0.7% and subsequently stabilized at about 0.4% (Fowler 1985b). Before 1970, male juvenile survival was closer to 10%, rather than 15%, below the expected rate from line PB in Figure 4. Between 1973 and 1975 the discrepancy between observed and expected (line PB) was about 20%.

Assuming that entanglement varied proportionately for all age classes of seals, all entanglement mortality rates in the model were reduced by one-third over 20 months (one-fifth per year) before 1970 and increased by the same amount for 1973 to 1975. Thus, an additional 10 to 20% of juveniles are assumed to die from entanglement by age 2. Entanglement mortality of all seals over 2 years is assumed to vary between 4 and 6% per year. The resulting pup production is compared to the observed in Figure 11. The fit to the observed is improved by this inclusion of variable entanglement rate in the model (compare Figs. 9 and 11).

If the same assumptions used for the simulation of Figure 11 are made, only with 2- to 3-year-olds suffering 8 to 12% mortality per year (an annual rate equivalent to the additional 15% lost over 20 months as juveniles ±20% of that value) while rates for seals over 3 remain at 4 to 6% per year, the resulting decline is as in Figure 12. This latter simulation brings the model population level down to the same level as the current pup counts on St. Paul Island indicate. Figure 13 shows associated total population numbers.

Model Predictions of Future Population Numbers

The model simulation of Figure 13 (and Figs. 8, 9, 11, and 12 as well) indicates that, while the current rate of decline is much slower than the 4 to 8% decline of the 1970's, the Pribilof fur seal population would continue to decline at about 1% per year for the next 50 years or more if mortality rates remain at current levels. If entanglement mortality were eliminated (and assuming pre-1960 survival rates still hold), the population could recover to the 1950's carrying capacity level after about 15 years, as evidenced by the increase from the late 1920's to the 1940's (Fig. 5). If current entanglement mortality rates (as assumed in Figs. 8 and 9) were halved for all age groups, the population could recover in about 50 years to a total of 1.61 million seals, 1.13 million total females, and 400,000 pups born, where the model population stabilizes (Fig. 14). This is a size equivalent to the observed population in 1960. If entanglement mortality rates were held at the levels assumed for the 1960's
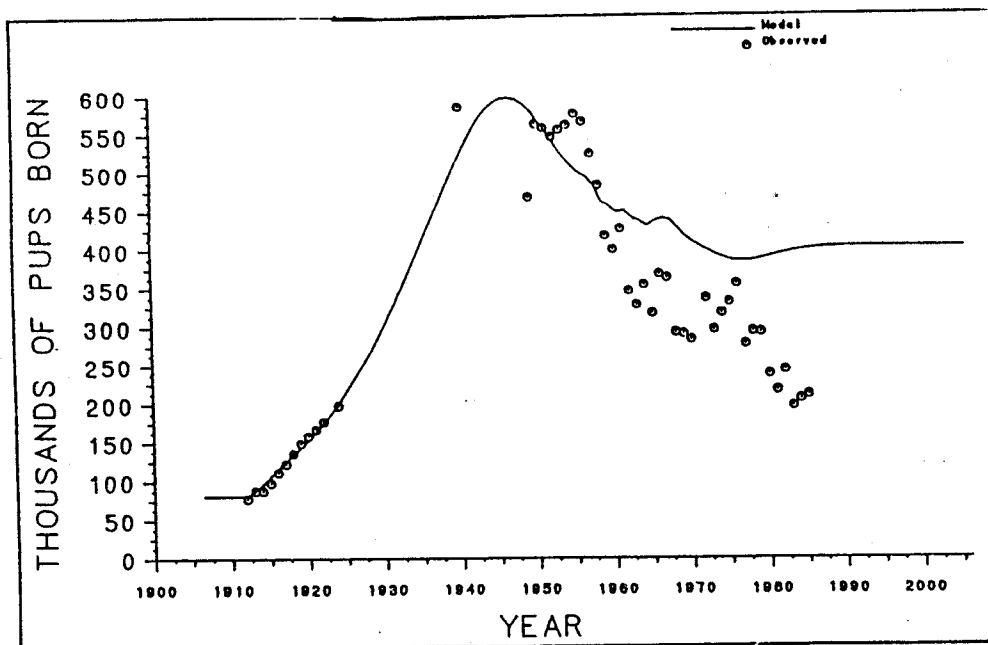
Figure 10.--Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-74) and, beginning in 1966, constant entanglement mortality of 15% before age 2, 5% from age 2 to 3, and no entanglement mortality over the age of 3 years.
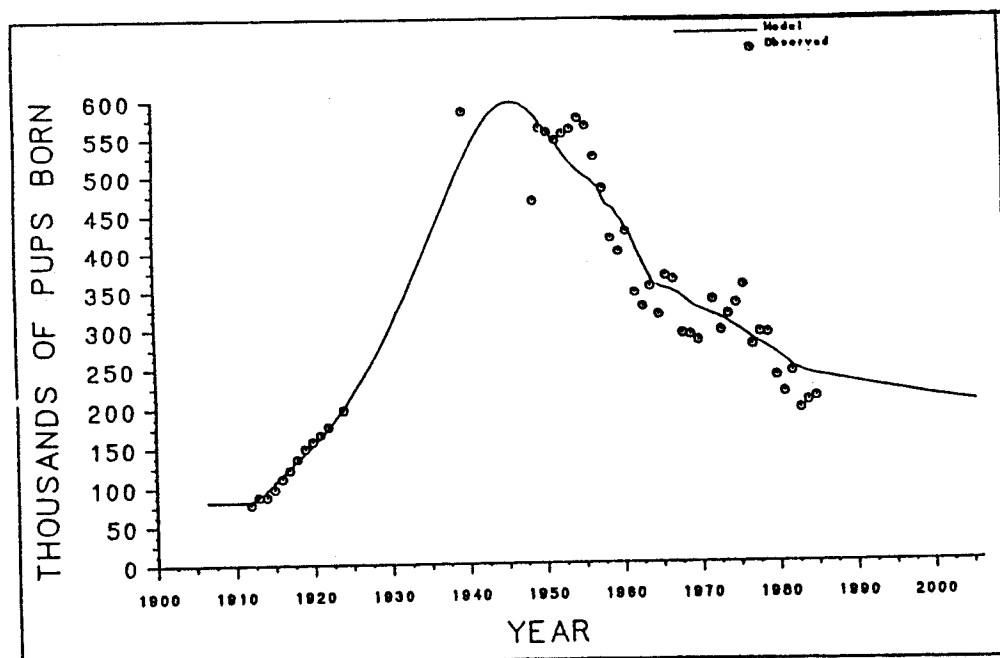

Figure 11.--Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-74) and variable entanglement mortality rates (10-20% before and 4-6% after age 2 years) beginning in 1960.
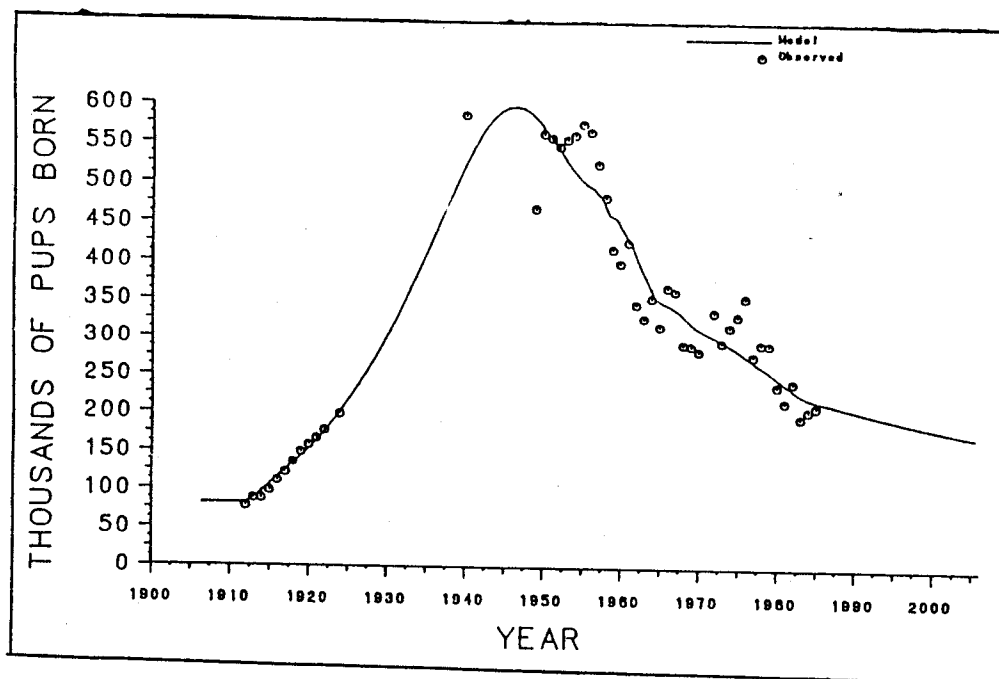
Figure 12.--Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-74) and variable entanglement mortality rates (10-20% before age 2, 8-12% between 2 and 3 years, and 4-6% after age 3 years) beginning in 1960.
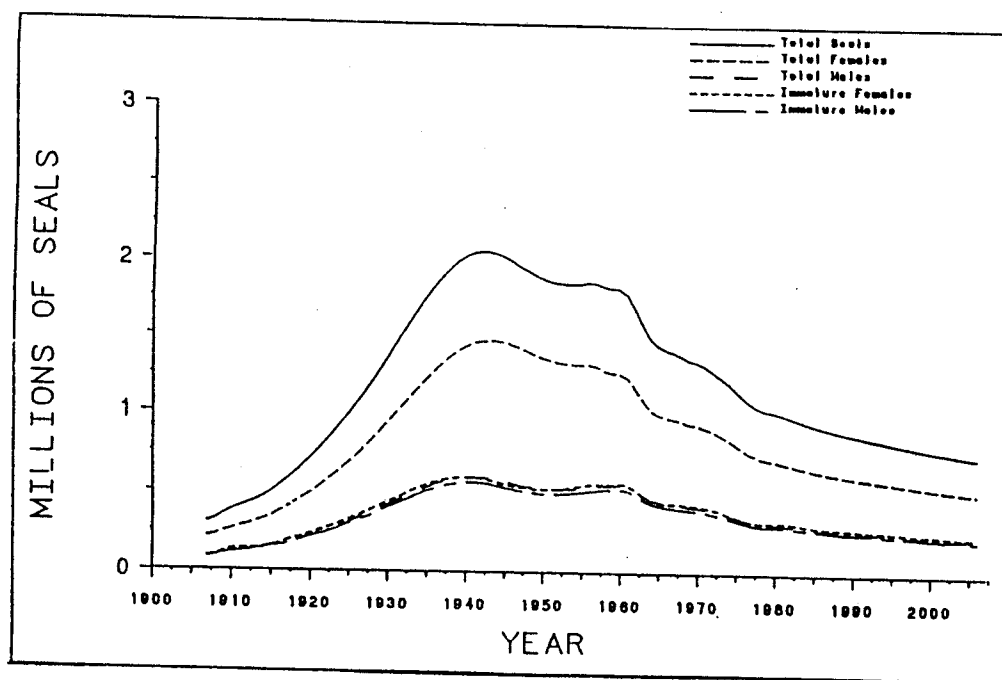

Figure 13.--Simulated population numbers (on 1 January) for the simulation of Figure 12.
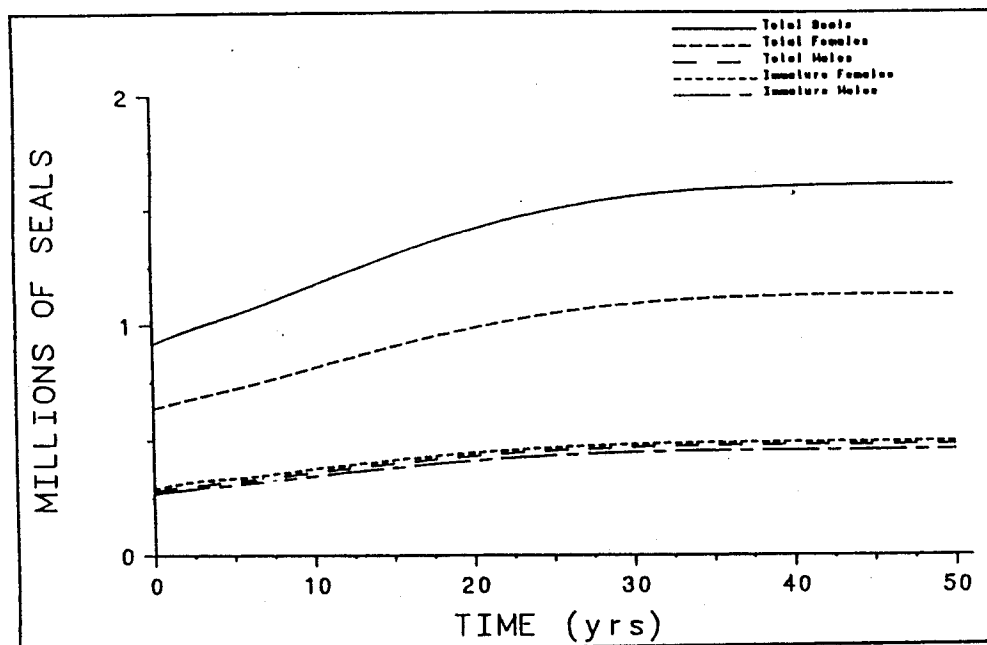
Figure 14.--Simulated population numbers (on 1 January) assuming that current entanglement rates are halved and after initializing with the estimated population size in 1987.

in the model run of Figure 12 (an additional 10% of juveniles die before age 2, 8% per year from age 2 to 3, and 4% per year over age 3), the population would increase slowly from present levels (917,000 total seals, 637,000 females, and 214,000 pups born in the 1987 simulated population) to 1.29 million seals, 896,000 females, and 301,000 pups born per year after 50 years and would stabilize at 1.34 million seals, 932,000 females, and 315,000 pups after 90 years.

DISCUSSION

The model results show that current estimates of pregnancy and natural mortality rates as outlined above are consistent with observational data from 1912 to 1958 if the ratio of female to male survival to age 3 is assumed to be 1.74. The model simulates the population increase from 1912 to the 1940's and predicts the appropriate carrying capacity level thought to have prevailed in the 1940's and 1950's. Lower estimates of the female-to-male juvenile survival ratio yield much lower equilibria and rates of population increase than have been observed on the Pribilofs. Clearly, the model is sensitive to female juvenile survival rate. However, this vital statistic is the least well known and least studied of all the vital rates involved. Tagging or other studies on female juveniles would greatly facilitate the estimation of their current survival rates.

Model sensitivity analysis shows that model results are also highly dependent upon the choice of the density-dependent relationship between pup mortality and number of pups born. The considerable variability associated with this functional relationship (Fig. 3) is undoubtedly due to the dependence of pup mortality on other factors besides total number of pups born. Actual pup density on the rookeries, climatic conditions, and competition with other species for food are other possible factors (which are not necessarily independent) which could be considered in developing more predictive functional relationships.

The model is relatively insensitive to changes in pregnancy rates and adult female natural mortality rates within the range of estimates available in the literature. Therefore, these vital statistics appear to be well enough known for modeling purposes.

The carrying capacity of the Pribilof Islands population appears to be regulated by the density of pups born on the rookeries. Subsequent survival as juveniles appears to be causally related to survival rate on land (Lander 1979, Fig. 4). This suggests that lower survival rate at higher population density is primarily due to reduced fitness of pups, whether by increased spread of disease, slower weight gain due to competition for food or space among lactating females, or other effects of crowding. The model is consistent with the view that there is no significant density-dependent control of mortality over the age of 2 years.

Owing to the weak density-dependent control of the fur seal population, the maximum pup production is at carrying capacity, not at a lower population size. This is in agreement with observations in the field during and after the period of female harvest in the late 1950's and 1960's.

The population decline after 1958 has been a subject of intense interest in recent years (e.g., Eberhardt 1981; Fowler 1984, 1985a, 1985b; Smith and Polacheck 1984; Trites 1984). The initial decline may be partially accounted for by the female harvest of 1956 to 1968 (York and Hartley 1981 and present model), but after 1960 it is evident that other factors are involved (Fig. 7). The model results suggest that entanglement mortality can account for the decline after 1960 if the following assumptions are made regarding female mortality (male mortality has no influence on pup production): An additional 15% of juveniles (less than age 3), on average, died from entanglement; an average of 5% of seals over age 3 suffered lethal entanglement; and significant entanglement mortality (at these rates) began in 1960.

The fit of the model to the observed pup counts is improved considerably if entanglement mortality rate is varied as a function of the entanglement rate observed in the subadult male harvest. A variation of ±50% of entanglement rate, i.e., 0.2 to 0.6%, appears to result in ±33% variation in the mean discrepancy between observed male juvenile survival rate and that predicted from line PB in Figure 4 (Fowler 1985a), or ±20% variation in entanglement mortality rate per year. If entanglement mortality rates of all age groups vary to this degree in proportion to

variation in observed entanglement rates, the appropriate curvature in the model pup curve after 1965 is produced.

The best fit is obtained if 2- to 3-year-old females are assumed to have suffered twice the entanglement mortality rates of males of the same age. If females over 3 years of age are assumed to not die at significant rates from entanglement, the decline in pups born since 1960 cannot be accounted for, and the model predicts that a stable population size of 1.49 million seals, 1.06 million females, and 401,000 pups born per year should have been reached by about 1985 (Fig. 10). Higher entanglement mortality of females as opposed to males of the same age could be accounted for if entanglement rate is a function of body size, rather than age as assumed by Fowler (1985a, 1985b). Even at 1 year of age, male fur seals are almost twice the size of females; a 3-year-old male is the same size as a 6-year-old adult female, and the largest females (up to 20 years old) are not as large as a 5-year-old male (Lander 1980a). This suggests that if entanglement is primarily a function of size, adult females could be expected to suffer the same entanglement rates as subadult males, perhaps 5% per year as estimated by Fowler (1985b), and immature females even higher rates. The assumption of 10% entanglement mortality rate for 2- to 3-year-old females is consistent with this hypothesis. Clearly, more information is needed on female entanglement rate and mortality as a function of age. The assumption that males and females of the same age suffer the same mortality rates is unlikely, especially given the disparity in size.

In the above analysis it is assumed that pups on land do not suffer entanglement mortality. In the model, pups of mothers dying from entanglement are assumed to die. Recent evidence reported by DeLong et al. (1988) suggests that mortality rates of pups may be increased by nonlethal entanglement of their mothers, since the females are less efficient at foraging and providing milk for the pup. However, as evident in Figure 3, pup mortality rates on land at a given density do not appear to have changed from 1914-65 to 1966-83, before and after the hypothesized onset of entanglement. Therefore, there is no evidence to support the hypothesis that nonlethal entanglement of lactating females has significantly affected pup mortality on land or the pup population as a whole.

As shown by the model results in Figure 14, a reduction of the current extrinsic mortality rate (due to entanglement or some other cause) by 50% would allow the fur seal population to recover at least partially. If this mortality is in fact due to entanglement, halving the current entanglement rate (to 0.2% from 0.4% of subadult males), which would reduce the annual entanglement mortality rate by 20%, would stop the current decline in pup production, according to model predictions. This suggests that it would be necessary to halve the density of plastic debris in the North Pacific and Bering Sea region to stop the decline and maintain the population at current levels.

The model results reported here suggest that the fur seal population can recover from single-event perturbations such as substantial harvest of the breeding population (females in the case of fur seals) or some other cause of mortality of finite duration. After the fur seal population was

reduced by 1912 to 15% of its carrying capacity level, the population was able to recover fully in 30 years. Recovery would be faster after smaller perturbations. However, long-term, continuous additional sources of mortality, such as lethal entanglement, form a much more serious threat to the population. While single-event perturbations are significant in the short term, chronic sources of additional mortality are much more important when considering the long-term stability of the population.

ACKNOWLEDGMENTS

REFERENCES

Briggs, L., and C. W. Fowler.
  1984. Tables and figures of the basic population data for northern fur seals of the Pribilof Islands. Background paper submitted to the 27th Meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission, Moscow, USSR, April 1984. [Available from C. W. Fowler, National Marine Mammal Laboratory, NMFS, 7600 Sand Point Way, N.E., Seattle, WA, 98115.]

Chapman, D. G.
  1961. Population dynamics of the Alaska fur seal herd. Trans. N. Am. Wildl. Nat. Resour. Conf. 26:356-369.

  1964. A critical study of Pribilof fur seal population estimates. U.S. Fish Wildl. Serv., Fish. Bull. 63:657-669.

DeLong, R. L., P. Dawson, and P. J. Gearin.
  1988. Incidence and impact of entanglement in netting debris on northern fur seal pups and adult females, St. Paul Island, Alaska. In P. Kozloff and H. Kajimura (editors), Fur seal investigations, 1985, p. 58-68. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-146.

Eberhardt, L. L.
  1981. Population dynamics of the Pribilof fur seals. In C. W. Fowler and T. D. Smith (editors), Dynamics of large mammal populations, p. 197-220. Wiley, N.Y.

Fowler, C. W.
  1984. Density dependence in northern fur seals (*Callorhinus ursinus*) of the Pribilof Islands, Alaska. Paper presented at the International Symposium and Workshop on Fur Seal Biology, 23-27 April 1984, Cambridge, England.

  1985a. An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 291-307. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

  1985b. Status review: Northern fur seals (*Callorhinus ursinus*). Presented at 28th Meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission, held in Tokyo, Japan, April 1985. Federal Register 50(44):9231-9248, Mar. 6, 1985.

Gentry, R. L., and J. R. Holt.
  1986. Attendance behavior of northern fur seals. Chapter 3. *In* R. L. Gentry and G. L. Kooyman (editors), Fur seals: Maternal strategies on land and at sea. Princeton Univ. Press.

Lander, R. H.
  1979. Role of land and ocean mortality in yield of male Alaskan fur seal (*Callorhinus ursinus*). Fish. Bull. U.S. 77:311-314.

  1980a. A life table and biomass estimate for Alaskan fur seals. *In* H. Kajimura, B. H. Lander, M. A. Perez, A. E. York, and M. A. Bigg (editors), Further analysis of pelagic fur seal data collected by the United States and Canada during 1958-74. Report submitted to 23rd Annual Meeting of the North Pacific Fur Seal Commission. Part 1, p. 44-57. National Marine Mammal Laboratory, NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

  1980b. Summary of northern fur seal data and collection procedures. Vol. 1. Land data of the United States and Soviet Union (excluding tag and recovery records). U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA, as No. PB 81-106502.

  1981. A life table and biomass estimate for Alaskan fur seals. Fish. Res. (Amst.) 1:55-70.

Lander, R. H., and H. Kajimura.
  1982. Status of northern fur seals. *In* Mammals in the sea, p. 319-345. FAO Fish. Ser. 5(IV).

Scheffer, V. B., C. H. Fiscus, and E. I. Todd.
  1984. History of scientific study and management of the Alaskan fur seal, *Callorhinus ursinus*, 1786-1964. U.S. Dep. Commer., NOAA Tech. Rep. NMFS-SSRF-780, 70 p.

Smith, T. D., and T. Polacheck.
  1984. The population dynamics of the Alaska fur seal: What do we really know? Report to National Marine Mammals Laboratory, NMFS, 7600 Sand Point Way N.E., Seattle, WA 98115, 122 p.

Swartzman, G. L.
  1984. Factors bearing on the present status and future of the eastern Bering Sea fur seal population with special emphasis on the effect of terminating the subadult male harvest on St. Paul Island. U.S. Marine Mammal Commission Report No. MMC-83/03. [Available from U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA 22161, as No. PB84-172329, 77 p.]

Trites, A. W.
  1984. Stock assessment and modeling of the North Pacific fur seal population. Final report to Canadian Department of Fisheries and Oceans, Contract No. OST83-00133, 82 p.

York, A. E.
  1979. Analysis of pregnancy rates of female fur seals in the combined United States--Canadian pelagic collections, 1950-74. *In* H. Kajimura, R. M. Lander, M. A. Perez, A. E. York, and M. A. Bigg (editors), Preliminary analysis of pelagic fur seal data collected by the United States and Canada during 1958-74. Report submitted to 22nd Annual Meeting of the North Pacific Fur Seal Commission, p. 50-122. National Marine Mammal Laboratory, NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

  1987. Northern fur seal, *Callorhinus ursinus*, eastern Pacific population (Pribilof Islands, Alaska, and San Miguel Island, California). *In* J. P. Croxall and R. L. Gentry (editors), Status, biology and ecology of fur seals. Proceedings of an International Symposium and Workshop, 23-27 April 1984, Cambridge, England, p. 9-21. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 51, 212 p.

York, A. E., and J. R. Hartley.
  1981. Pup production following harvest of female northern fur seals. Can. J. Fish. Aquat. Sci. 38:84-90.

STUDIES OF THE POPULATION LEVEL EFFECTS
OF ENTANGLEMENT ON NORTHERN FUR SEALS

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ABSTRACT

Recent studies have focused on entanglement among the juvenile male northern fur seal, *Callorhinus ursinus*, as a means of evaluating the effects of entanglement at the population level. Most entanglement-related field studies were conducted on St. Paul Island, Alaska, in the 1980's but the analyses include relevant data from the late 1970's. Reported here are the results of recent studies on monitoring of entanglement, estimates of entanglement-caused mortality, and the effects entanglement may have on the chances an animal is observed on the breeding islands.

The observed proportions of seals entangled in 1985 and 1986 were consistent with those observed during the last few years of the commercial harvest (about 0.4%). The proportion observed in 1988 was 0.29%, the lowest observed since 1970. The change reflects a drop in the numbers of animals entangled in fragments of trawl webbing. The frequency of occurrence of trawl webbing among the entangling debris was about half the former levels whereas the proportion of seals entangled in other types of debris did not change.

These studies confirm earlier estimates indicating that, after 1 year, the survival of seals entangled in debris light enough to permit the animals to return once to land is about half of the survival of nonentangled seals. Data indicate that the main factor contributing to the success of entangled animals that do survive is escapement from the debris.

Rates at which entangled animals are resighted indicate that the proportion of animals resighted drops with an increase in the size (weight) of debris.

Data from radio-tagged seals confirm that entangled seals go to sea for longer periods of time than do controls.

INTRODUCTION

Entanglement in marine debris, specifically in plastics associated with the commercial fishing industry, has been documented for a number of species of seals and sea lions (Fowler 1988). The effects of entanglement in such debris have been the subject of a number of studies, especially as related to the impact on the northern fur seal, *Callorhinus ursinus*. Many of these studies have examined effects at the population level (Fowler 1982, 1985, 1987; Swartzman 1984; French and Reed 1990; Swartzman et al. 1990). Others have studied the effects at the level of the individual (Fowler 1988).

Entanglement of northern fur seals in marine debris has been a concern for several decades. The first sightings of entangled seals occurred just after World War II. Records of entanglement among young males taken in the commercial harvest or seen in juvenile male roundups have been maintained since 1967. Concern about the potential role of entanglement-caused mortality has given rise to research focused on determining as clearly as possible the extent to which entanglement contributes to a reduction in survival and to declining trends in the population (Swartzman 1984; Fowler 1985, 1987; French and Reed 1990; Swartzman et al. 1990).

This paper reports on recent field work to assess the effects of entanglement on the population of northern fur seals breeding on St. Paul Island, Alaska. The objectives of this work are: (1) continued monitoring of the proportion of seals entangled, (2) determination of the nature of entangling debris, (3) determination of the mortality caused by trawl webbing, especially as related to effects at the population level, and (4) assessment of the relative rates at which entangled and control animals are resighted. Part of the study of relative rates of resighting addresses the question of whether or not an animal's chances of being seen again are altered by being, or having been, entangled.

METHODS

Most of the data treated in this study deal with young male fur seals of the size (roughly 105 to 125 cm in total length) formerly taken in the commercial harvest on St. Paul Island. The commercial take of fur seals, which ended in 1984, was the earliest source of data on entanglement. Other data, as the main focus of this paper, were collected during 1985, 1986, and 1988 from animals of the same size (and same approximate age) to ensure comparability with historical data. Males of this size are usually between the ages of 2 and 5 years, mostly 3-year-olds.

The studies reported here involved roundups, a procedure conducted during the breeding season. A total of 63 roundups were conducted in July and early August 1985. Sixty-one were conducted in July and early August 1986; 66 were completed during July 1988.

During roundups, young males are herded together to be examined for debris or tags and for applying tags. To conduct a roundup, field biologists approach an area (called a hauling ground) near a breeding

rookery where young males come ashore in large numbers. Avoiding disturbance to the rookeries, the members of the research team position themselves between the hauling ground and the water. The males on the hauling ground are then surrounded and herded away from the rookery but close to the water's edge. Care is taken to minimize the movement required of the animals and to allow them sufficient space to prevent crowding and overheating.

Once the seals are in a controlled group, field workers then allow small numbers of animals to leave the group and file toward the water. Once one or more seals begin moving toward the water, other seals follow. This movement is controlled (to ensure that tagged flippers will be seen) by the field crew. While moving toward the water, seals pass between observers, some of whom are engaged in counting seals while others watch for tags and entangling debris. Others of the field crew remain prepared to capture seals, while the remainder work to assure that the main group of seals remains in place.

When an entangled or tagged seal is seen among those leaving, the movement of seals from the main group is stopped. If tag numbers cannot be read, if tags are to be applied, or if a detailed examination of the debris is required, the seal is captured with a wooden pole fitted with a rope noose (<2% of these seals escape to the water without being captured). If tags are to be applied, or the debris examined in detail, the seal is placed on a restraint board (Gentry and Holt 1982) for a few minutes. Tags are applied on the trailing edge of each foreflipper, about 2-3 cm distal from the hairline.

If the captured animal is entangled, the nature of the entanglement is recorded (and tags applied if not previously tagged). Data recorded at the time of tagging include the tag number; the color, size, and type of debris; mesh size (if it is a net fragment); and the extent of the wound the debris has caused. A sample of the debris is removed (if there is enough) to be used later for measuring twine size and for any analysis necessary for identification of the plastics involved.

Two control seals about the same size as the entangled animal are also tagged to compare rates of return in succeeding years. The choice of tagging two control seals is arbitrary. Tagging more controls than entangled seals ensures a larger sample of returns to be used in comparing the relative rates of return of the two groups. It also aids in the study of the frequency of resighting rates and the locations (for study of intermixture) of resighted seals.

In most cases, seals that are not handled and seals released after being tagged or examined return directly to the water. By the end of the roundup, all seals have returned to the water.

Some of the animals seen in the first roundup are seen again in later roundups. The resulting sampling scheme is one of sampling with replacement, and the data for both the control animals and the entangled animals are treated accordingly.

Other sets of the data reported in this paper are from similar studies prior to 1985 in which animals were sighted in the commercial harvest prior to 1985. During the harvests, animals were herded together and moved to special areas where they were killed. These data from harvests, therefore, are treated as samples without replacement.

In previous studies of fur seal entanglement, two approaches have been used to categorize debris on seals according to its size (weight). For continuity and comparison, both are used in this study with distinction depending on the terms used. The first approach divides the debris into "light" or "heavy" categories depending on whether it is light enough for the entangled seals to return (at least once) to the breeding islands or so heavy that they cannot return. This definition suffers from lack of precision because the two categories are not discrete; their overlap is dependent on factors such as how far the seal has to swim to haul out on land. The upper limit of the light category is about 400 g, since over 90% of the entangled seals observed on land are in debris that weighs <400 g (Fowler 1987).

The second approach uses three distinct weight categories. The debris seen on animals is either weighed (after being removed) or subjectively evaluated (when entangled animals are released with debris intact). The weight of debris is classified as small (<150 g), medium (between 150 and 500 g), and large (>500 g).

To study the behavior of entangled animals, and the influence of entanglement on the chances of being resighted, radio transmitters (weighing about 40 g) were attached to 16 control and 16 entangled animals to monitor their presence and absence in the vicinity of the hauling grounds or rookeries. A radio transmitter was attached with epoxy glue to the back of the animal's head while the animal was restrained following procedures described in Loughlin et al. (1987). Each radio-tagged seal was also marked with bright paint applied to the radio and glue. Each radio was a 3.5-V transmitter, manufactured by Advanced Telemetry Systems, Inc. All radios transmitted within the frequency range of 164 to 166 MHz.

Data on the behavioral effects of entanglement were all collected in 1988. After attaching radios early (17 to 26 July), observers, using hand-held receivers, listened for radio-tagged seals during a daily visit to each haulout site until 29 August. A computer attached to a receiver was set up at the southern end of St. Paul Island (Reef Point) to scan for and record radio signals from each of the radio-tagged animals within receiving distance (approximately 5 km).

The amount of time the seals spent on shore was estimated in two ways. Detailed data for seven animals (three control and four entangled) were available from the computer at Reef Point. The computer scanned for the presence of these animals for 10 sec every 15 min, 24 h/day. We estimated the duration of intervals spent on land or at sea to the nearest quarter hour. Because the signals occasionally were blocked by the animals lying on the transmitters, and because the animals frequently entered the near-shore water without going to sea, we considered an animal to be at sea only

when its transmitter had not been heard for at least an hour. Hence, by this definition, trips to sea could never be shorter than 1 h.

The second method for estimating the time ashore involved the use of data obtained from observers with hand-held receivers. If the radio on a given animal was heard during a survey, the seal was considered to have been on land all day. If the signal from that radio was not heard, the seal was considered to have been at sea all day. When the signal from a given animal was heard one day but not on the next day, we assumed that the animal had departed halfway between the two observations. This gave us an onshore estimate to the nearest half day for all 32 animals.

Standard methods were employed in conducting the usual statistical tests (e.g., chi-square tests) where noted. The level of significance chosen for statistical tests was $P = 0.05$, unless otherwise noted. The analysis of data resulting from the resighting of tagged animals involved both standard approaches (e.g., the Seber-Jolly method; Seber 1973) and a regression analysis specifically designed for this study. The latter was developed to make use of all the existing data to address questions unique to this study. The specifics of the procedure used in this analysis, with the assumptions involved in estimating survival from entanglement-caused mortality, are presented in the Appendix.

RESULTS

During 1985, 1986, and 1988, 22,211, 22,572, and 24,519 (respectively) male seals of the size conventionally taken in the harvest were sampled. As will be presented in more detail below, about 25% of these totals were repeated sightings. Table 1 shows the numbers of seals that were tagged each year and percentage resighted in subsequent years.

Of the 49 tagged animals released in 1985 and resighted in 1986, 12 (24%) were originally tagged as entangled animals. The change from a ratio of 85:172 (85/172 = 0.494, entangled to controls) tagged in 1985 to 12:37 (12/37 = 0.324) resighted in 1986 is not statistically significant (chi-square test). There was no field effort in 1987, so no samples were collected in that year. Of the 14 seals tagged in 1985 and resighted in 1988, 1 (7.7%) had been tagged as entangled. The change in ratio from 85:172 (85/172 = 0.494) to 1:13 (1/13 = 0.077) between 1985 and 1988, and from 12:37 to 1:13 (12/37 = 0.324 to 1/13 = 0.077) between 1986 and 1988 are statistically significant (binomial probability tests).

Of the 407 animals tagged in 1986, 128 (31.4%) were entangled. Of 46 seals tagged in 1986 and resighted in 1988, 6 (13%) were tagged as entangled seals in 1986. The change from a ratio of 128:279 (128/279 = 0.459) to 6:40 (6/40 = 0.150) between 1986 and 1988 is also statistically significant (chi-square test).

Of the eight seals resighted in 1988 after having been tagged as entangled in earlier years (including one tagged prior to 1985), six had lost their entangling debris. No seals have been resighted as entangled after originally having been tagged as controls.

Table 1.--Comparison of numbers of tags applied (in parentheses) and resighted (percent resighted shown in brackets below the numbers resighted) by year for entangled and nonentangled seals, each row corresponding to the tags released in the first year for that row (from Fowler et al. 1989).

	Year			
Controls	1985	1986	1987	1988
Nonentangled	(172)	37 [21.5]	-- --	13 [7.6]
		(279)	-- --	40 [14.3]
			-- --	-- --
				(104)
Entangled	(85)	12 [14.1]	-- --	1 [1.2]
		(128)	-- --	6 [4.7]
			-- --	-- --
				(52)

Table 2 presents the percentage of juvenile male seals found entangled, by year, for 1981 to 1988 in terms of the kinds of debris in which they were entangled. More detailed presentations of the data for 1988 are available in Fowler et al. (1989). Figure 1 illustrates the percentage of entangled seals observed in the harvests since 1967 and in the roundups since 1985. Table 2 also shows the composition of the debris found on animals in terms of proportions entangled. The proportion entangled in 1988 was the lowest observed since 1970 and was about half of the mean proportion observed from 1981 to 1986.

The frequency distribution of the size of debris seen on the animals per year is shown in Table 3. The numbers and percentages of those animals resighted in subsequent years, in relation to the size of debris, are presented in Table 4. None of the seals entangled in large pieces of trawl webbing were resighted more than 1 year subsequent to their being tagged,

Table 2.--Debris found on juvenile male fur seals in 1988 compared to 6 earlier years, expressed as the observed percent of juvenile male seals entangled by debris category.

Type of debris	Entanglement (%)						
	1981	1982	1983	1984	1985	1986	1988
Trawl net fragments	0.29	0.24	0.30	0.22	0.36	0.27	0.15
Monofilament net fragments	0.00	0.01	0.01	0.02	0.01	0.01	0.00
Plastic packing bands	0.08	0.10	0.07	0.09	0.05	0.06	0.07
Cord, rope, string	0.04	0.04	0.02	0.05	0.08	0.07	0.05
Miscellaneous items	0.03	0.01	0.03	0.01	0.01	0.01	0.01
Total	0.43	0.41	0.43	0.39	0.51	0.42	0.28
Sample size	102	102	112	87	76	70	53

Table 3.--Annual percentage frequency distribution of the size of debris on entangled seals that were tagged and released.

Year	n	<150 g(%)	150-500 g(%)	>500 g(%)
1983	84	63	23	14
1984	57	81	12	7
1985	78	72	20	8
1986	128	72	21	7
1988	53	72	15	13
Total	400	71	19	10

whereas seals in small debris were resighted up to 5 years later. The resighting rate of animals in medium-size debris was intermediate to those for large and small debris.

A summary of the results of the radio tagging study using hand-held radio receivers is presented in Table 5. The table contains data from both full and partial records because the study was of insufficient length to encompass an entire long feeding trip for all of the tagged seals. Furthermore, almost no seal completed a full cycle, from departure on a trip to sea followed by a return and an on-land interval until departure for the next feeding trip. For that reason, the estimated percentages of time spent on land during the course of this study may be different from those over an entire season spanning several full cycles. However, the entangled seals spent more time at sea than did controls. Twelve of sixteen entangled
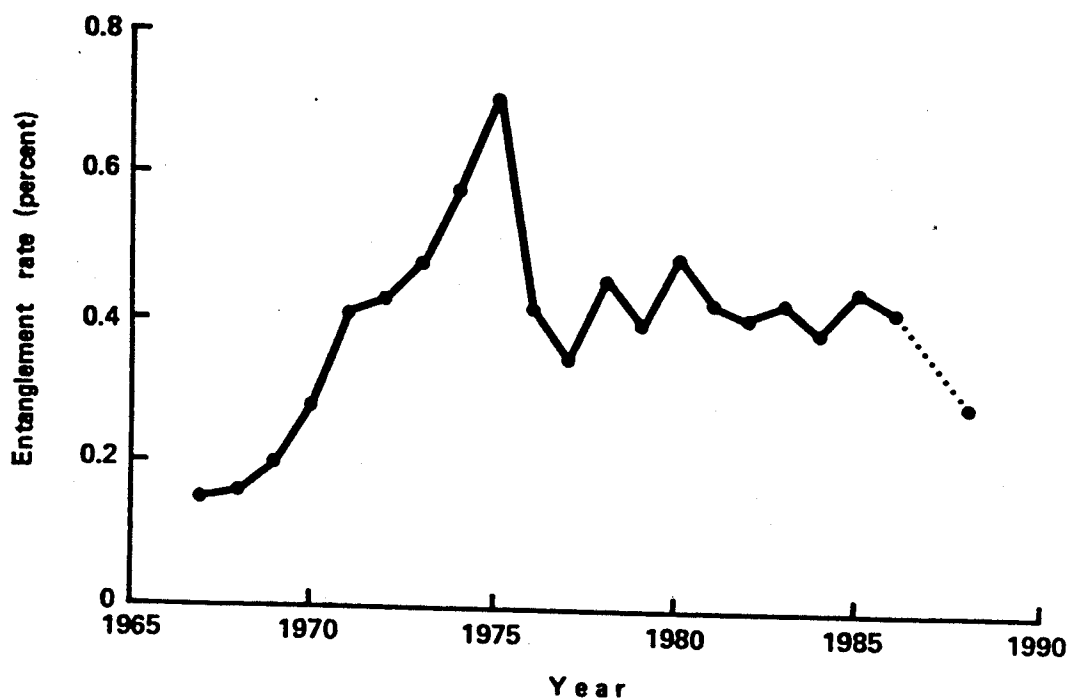
Figure 1.--The percentage of juvenile male seals found entangled in the commercial harvest from 1967 to 1984 and in research roundups from 1985 to 1988, on St. Paul Island, Alaska.

Table 4.--The numbers and percentages of tagged animals listed in Table 3 that were resighted by year in relation to size of entangling debris and year.

Year tagged	Year resighted	Size of debris		
		<150 g(%)	150-500 g(%)	>500 g(%)
1983	1984	18(34)	3(16)	2(17)
1983	1985	4(8)	1(5)	0(0)
1983	1986	3(6)	0(0)	0(0)
1983	1988	1(0)	0(0)	0(0)
1984	1985	14(30)	2(29)	0(0)
1984	1986	9(16)	0(0)	0(0)
1984	1988	0(0)	0(0)	0(0)
1985	1986	9(16)	3(19)	0(0)
1985	1988	1(2)	0(0)	0(0)
1986	1988	6(7)	0(0)	0(0)
Combined years		65(23)	9(12)	2(5)

Table 5.--Comparison of the percent of time spent
on land (present) and at sea (absent) for entangled
and control seals fitted with radio tags. Data are
from daily surveys with hand-held receivers on all
hauling areas on St. Paul Island.

Seals[a]		Percent of time	
		Present	Absent
Entangled-fr	(N - 4)	35	65
Controls-fr	(N - 13)	28	72
Entangled-pr	(N - 12)	13	87
Control-pr	(N - 3)	10	90
Entangled-t	(N - 16)	19	81
Control-t	(N - 16)	25	75

[a]fr - males with full records, pr - males with partial
records, and t - all males combined.

seals had not returned to land by the end of the study, whereas only 3 of
16 control seals had not returned (chi-square test, $P < 0.005$, or 0.001
with continuity correction). Typically, both entangled and control seals
made several short trips while in the vicinity of St. Paul, and then
departed on one long feeding trip. Selecting this longest trip to sea for
each seal, we found that the entangled seals had significantly longer trips
(30.9 days) than did controls (24.3 days). For seals that did not return
from their long trips, the time from departure until the end of the study
was used. Therefore, these were actually minimum estimates of their trip
lengths.

The hand-held receivers could not detect the short trips taken between
daily scans. Thus, the proportion of time on land (Table 5) actually esti-
mates the time when the seals were in the vicinity of St. Paul, but not
necessarily ashore. However, the data collection computer, which was able
to detect short trips for seven seals, provided estimates of the time actu-
ally spent ashore at Reef Rookery. These data indicated that the four
entangled animals spent a smaller proportion (44.8%) of their visit to St.
Paul on land than did the controls (55.3%), but the difference is not sta-
tistically significant. The mean time between the application of tags and
the departure to sea for a long feeding trip for entangled animals was 7.59
days; that for the controls was 6.17 days (no significant difference).

In 1988, 7 of 16 entangled seals fitted with transmitters were
resighted in subsequent roundups. Four of sixteen controls with trans-
mitters were resighted. There is no significant difference between these
rates of resighting (chi-square test).

Analyses of the data in Table 1 are possible through the application of two very similar methods described in Brownie et al. (1978) and the Seber-Jolly method (Seber 1973). These methods result in estimates of survival of both categories of seals (entangled and controls). The annual survival of entangled seals estimated by these two methods (the same for each) is 0.22 (0.95 confidence limits of ±1.00, assuming a Poisson distribution for the resightings), and 0.51 (0.95 confidence limits of ±0.446) for controls. Although not statistically significant, the estimated survival for the entangled animals given by these results is 42% that of the controls. The estimated survival for the controls (0.51) is lower than the estimates of survival produced by Lander (1981) for juvenile males (about 0.8, including the effects of unobserved entanglement), but the difference is within the confidence limits shown above.

We also used the data in Table 1 in a regression analysis to estimate the ratio of the probabilities of being resighted for entangled and control animals and the survival factor associated with entanglement in light debris. The basis of the regression analysis is demonstrated in Figure 2, which shows the declining rate at which entangled animals were resighted relative to the controls. Each data point is corrected for the ratio of entangled to nonentangled animals, as shown in Table 6.

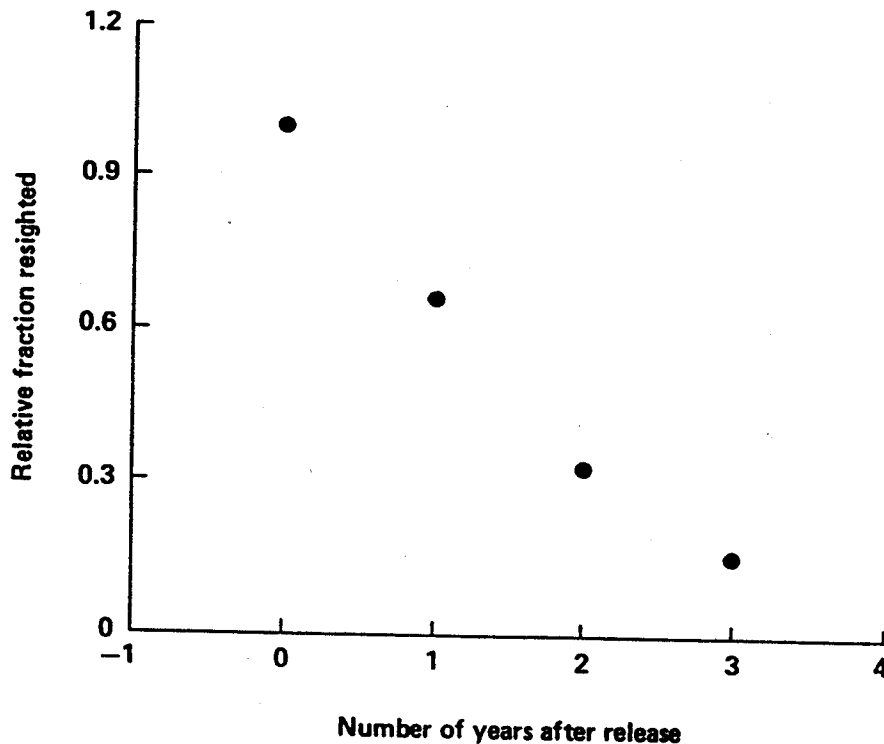Figure 2.--Relative rates of return for entangled juvenile male fur seals compared to controls (nonentangled tagged seals) for varying time intervals. The relative rate of return is $F*(C/D)$ = $P_{i,k}(N_{c,i}/N_{e,i})$ and the time interval is $x = (k-i)$, from Table 6 and Appendix. The point at time zero, with an adjusted ratio of entangled to control animals of one, was not used in the regression analysis.

Table 6.--List of data as extracted from Table 1 for regression analysis to estimate entanglement related survival; for a linear model of y = a + bx. See Appendix for details.

A Year i	B Year k	C $N_{c,i}$	D $N_{\bullet,i}$	E $\ln(N_{c,i}/N_{\bullet,i})$	F $P_{i,k}$	G $\ln(P_{i,k})$	y E+G	x B-A
1985	1986	172	85	0.7048	0.3243	-1.1260	-0.42	1
1986	1988	279	128	0.7792	0.1500	-1.8971	-1.12	2
1985	1988	172	85	0.7048	0.0769	-2.5649	-1.86	3

The results of the regression analysis, with the assumptions involved in estimating survival from entanglement-caused mortality, are presented in the Appendix. The estimated annual survival of seals entangled in light debris is about half (0.49) that of nonentangled seals. The probability of resighting an entangled seal was estimated to be about 1.35 times as great as the probability of resighting a control (given that they are both alive). However, this estimate is not significantly different from 1.0 (the case where the probabilities of seeing a seal from either group are the same).

It should be made clear that the total annual survival among entangled animals (including the effects of other sources of mortality along with those due to entanglement) is the product of natural survival and survival from entanglement. If we use the survival for juvenile males from Lander (1981)--about 0.8--the overall survival for seals entangled in light debris would be about 0.4 (i.e., about 0.8 × 0.5 = 0.4 for 3-year-old males). This is a higher survival rate than that from the Seber-Jolly analyses presented above (0.22).

Table 7 contains data on the frequency of resighting tagged seals during the season when tags were applied. These data show that the fraction of resighted control animals is nearly the same as the fraction of resighted entangled animals (both being about 25%). No statistically significant differences were found between the rates of resighting for entangled and control animals for any year or for the total (chi-square tests).

DISCUSSION

Although there is insufficient information to draw conclusions, the data collected in 1988 on St. Paul Island suggest a decline in the proportion of juvenile male northern fur seals that are entangled. Most of the change seems to be associated with a reduction in entanglement in trawl webbing, possibly a reflection of reduced occurrence of trawl webbing among pelagic debris as reported in 1988 by Japanese scientists (Fowler et al. 1989). The proportion of seals entangled in other forms of debris seems to be about equal to the proportion observed in the past 7 years. The differences between 1988 and previous years may be a result of changes in the

Table 7.--Comparison of numbers of tags applied to entangled and control juvenile male fur seals in 1985, 1986, and 1988 with the numbers in each category resighted the same season. The numbers in parentheses are the percent of the tags applied that were resighted.

| | | Number of tags | | | |
| | | Controls | | Entangled | |
Year	Applied	Resighted		Applied	Resighted
1985	170	35(20.6)		76	21(27.6)
1986	165	54(32.7)		70	19(27.1)
1988	104	21(20.2)		52	15(28.8)
Total	439	110(25.1)		198	55(27.8)

rate of loss and discard of net fragments. Various education programs at national and international levels have been in place for several years, and international regulations prohibit the discard of such debris.

Severe wounds caused by prolonged entanglement in light debris contribute to death. Bengtson et al. (1988), demonstrated that pups become entangled in net fragments with mesh sizes much smaller than those seen on the subadult males in the roundups. The subsequent growth of those seals caught in debris light enough for them to survive the effects of drag in the water then results in wounds and death. Seals remaining entangled in debris often suffer from wounds that increase in size as a result of the seals' growth (DeLong et al. 1990). The degree to which wounds and resulting infections contribute to mortality in comparison to other sources of mortality caused or accentuated by entanglement (such as starvation, strangulation, and predisposition to predation) cannot be determined from existing data.

Some seals survive because they escape from the debris. Escape has been reported for animals resighted in other studies (Scordino 1985; Fowler 1987), some within the season during which animals were tagged. Of the total of eight seals resighted in 1988 after having been tagged as entangled in earlier years, six had lost their entangling debris. How this affects estimates of survival of seals in light debris has not been determined; conceivably, individuals that have lost their debris would be resighted with the same probability as control animals.

All debris on entangled animals that was later lost had been judged to weigh <150 g at its first sighting; otherwise it was similar to commonly observed debris. One possible explanation for this pattern is that the animals in small debris are the most likely of the entangled animals to

return to the breeding islands. There they can come into contact with substrates (such as rocks) where the debris can abrade or otherwise wear to the point of breaking and falling off. Such wear is noted on the debris on many of the seals seen in the roundups, and on a few occasions debris has broken and fallen off during the handling of entangled animals. In view of the small numbers of animals resighted as entangled and the low survival of entangled animals, it would appear that most animals that remain entangled eventually die as a result of the debris.

The relative rate of resighting of animals originally tagged as entangled varies with the size of debris. A statistically significant (chi-square) decline in the rate at which seals are resighted with increasing size of debris is seen in Table 4. Corresponding information reported by DeLong et al. (1990) shows that of 17 females experimentally entangled in 200-g fragments of trawl net, 2 (12%) returned to the same rookery to give birth 1 year later. This is equal to the 12% resight rate of the seals entangled in medium-sized debris (Table 4). Thus, factors such as exhaustion, starvation, and drowning (likely acute factors at sea) appear to be increasingly important in the causes of death due to entanglement as debris size increases. If the survival of seals in large debris is proportional to the rate at which they are resighted, the survival of those in debris weighing just over 500 g would be about one-fourth (5/22) the survival of those in small debris. Therefore, survival resulting from the effects of entanglement alone would be about 0.11 ((5/22) × 0.49 = 0.11; using the 0.49 from the Appendix). Assuming survival from natural causes is 0.8 (Lander (1981), whose results may include some mortality due to entanglement), the total survival for this large-debris group is calculated as 0.09 (0.8 × 0.11 = 0.088). This implies a turnover in the population of about 2.4 times per year (turnover meaning the number of entangled seals that die for every entangled seal occurring in the population, and being equivalent to the instantaneous mortality rate, or the negative natural log of survival; -ln 0.09 = 2.42). Presumably, following the trend in Table 4 to even larger debris, the turnover rate continues to increase with the size of entangling debris. If the estimated survival for controls from the Seber-Jolly analyses presented above were used (0.51 in place of 0.8), this estimated turnover would be even more rapid.

Seals that are entangled in large debris may find it impossible to return to land. Seals are seen entangled at sea in debris that is clearly large enough to prevent their returning to land (Fowler 1987). This is important in interpreting the information in Table 4. The number of seals entangled in large debris resighted on land may be small not because the seals thus entangled have died soon after entanglement, but because the debris prevents them from returning to the islands to haul out. This effect would be greater with increasing size of entangling debris. Such a trend would affect estimates of entanglement-related mortality. However, failure to return has the same effect on the population as mortality; an animal that does not return to its breeding colony is removed from the reproductive population.

Whether or not a seal is entangled may affect its chances of being seen in roundups. This is important in estimating the proportion of seals

entangled and their survival rates. Factors that may affect estimates include: 1) time spent on land and at sea, 2) entangling debris or scars attracting the attention of observers, 3) relative proportions of the two groups which remain at sea for the entire season, a factor about which nothing is known, and 4) probability of seeing seals that have lost entangling debris compared with the probability of seeing entangled seals.

Entanglement results in prolonged at-sea portions of the feeding cycles for northern fur seals. Previous work on radio-tagged entangled male seals showed that the pelagic phase of feeding cycles was about twice as long for entangled seals as for controls (Bengtson et al. 1989). The results of this study are consistent with this effect of entanglement. Similar results have been noted for females (DeLong et al. 1990). It has not been possible to produce accurate estimates of the effects of entanglement on the portion of time spent on land. As a consequence, the relative time spent on land (as a fraction of the complete feeding cycle) remains undetermined. Thus, it is not possible, with the data from radio tagging, to quantify the effect of altered feeding cycles on the chances of a seal being seen.

Other data concerning the probability of resighting a seal are inconclusive. Based on data in Table 7, it would appear that once seals return to the islands, entanglement does not significantly affect their chances of being seen at least twice. Such a comparison can also be made with the smaller sample of radio-tagged animals (these seals being more visible with the bright paint). In 1988, no significant difference was found in the rates of resighting entangled and control seals fitted with transmitters in subsequent roundups.

Based on conventional mark-recapture analyses and results presented in the Appendix, seals entangled in light debris experience an annual survival that is about half (0.41 to 0.49) that for control seals. Previous estimates are very similar (0.42, Fowler 1987; 0.46, Fowler 1985.)

Regardless of a seal's probability of being resighted, it is obvious that entangled seals suffer higher mortality than do controls (Fig. 2). We have considered whether the reduced relative rates of resighting between initial release and the first resighting (e.g., the change between the first two points in Fig. 2) could have been due only to differences between the probabilities of seeing entangled or control seals. Both groups would have experienced similar survival, and the change would have been entirely due to a higher probability of seeing control animals. If this were the case there would be no further changes in the ratios over time. A level relationship would emerge between the points for years 1-3, all of which would be lower than the ratio at year 0, the time of release. The continued decline is indicative of the predominate effect of lowered survival among entangled seals.

Combined with other factors, the mortality caused by entanglement in light debris lowers the total survival for juvenile males entangled in light debris to about 0.39, assuming independence of the causes of mortality and a natural survival of 0.8. Each year, then, the number of

seals in light debris that die would be about the same as the number of seals in light debris that are estimated to be alive in the population at the time of sampling (94% as many, based on a turnover of 0.94 from $-\ln(0.39) = 0.94$, as the instantaneous rate of mortality).

A great deal of progress has been made in understanding the extent and effects of entanglement in marine debris on northern fur seals. However, precise estimates of the contribution of entanglement to the survival and trends at the population level have yet to be produced. Several studies indicate that young fur seals are more likely to become entangled than larger seals. Pups can become entangled even before leaving land (DeLong et al. 1988). Pups have been observed entangled or becoming entangled in large fragments of debris. Groups of pups often become entangled together or in succession (Fowler 1987; DeLong et al. 1988). Experiments show that pups are susceptible to entanglement in about four times as much debris as older animals because they can pass their heads through net fragments of smaller mesh size (Fowler 1987; Bengtson et al. 1988). A greater propor- tion of entangled animals among the young (also less experienced) seals is also consistent with the view that immature seals are more curious than older seals and are, therefore, more likely to be attracted to debris in which they may become entangled.

Research continues to show that mortality rates are quite high for seals that become entangled in larger debris. The results of the studies reported here indicate an annual survival (from the effects of entangle- ment) of about 0.09 for seals in debris weighing just over 500 g. Combined with the potential that larger net fragments have a higher probability of attracting seals and the fact that seals have been observed entangled in groups in large debris (Fowler 1985; DeLong et al. 1988), entanglement in large debris obviously deserves attention. However, logistic and financial constraints have made such studies impossible.

The need for studies to examine this problem is emphasized by the implications of previous attempts to account for the effects of large debris. Trawl webbing accounts for about two-thirds of the light debris (Table 2), so the portion of the juvenile male population entangled in light pieces of trawl webbing has been (before 1988) about 0.003 ($0.66 \times 0.004 = 0.00264$; 0.004 being the proportion entangled in light debris of all kinds). On beaches, at sea, and on entangled animals seen away from the breeding colonies, the frequency of occurrence of pieces of heavy trawl webbing is about five times that of light (Fowler 1987). Assuming, that for every piece of light debris on an entangled seal there are five pieces of heavy debris also entangling seals, then entanglement in heavy debris involves about 1.5% of the juvenile male population ($0.003 \times 5 = 0.015$).

As mentioned above, pups during their first few months at sea may be four times more susceptible to entanglement than juvenile males. If so, 6% of their numbers become entangled each year ($4 \times 0.015 = 0.06$). Accounting for the turnover from mortality of seals in large debris (estimated earlier as 2.4 times per year for debris just over 500 g) produces the implication of an entanglement-caused mortality of over 14% ($2.4 \times 0.06 = 0.14$). This does not account for the mortality in light debris. Entanglement in

heavier debris has been observed to involve more than one animal per piece
(Fowler 1985, 1988; DeLong et al. 1988). This, combined with the greater
attraction large debris must have for seals (the larger pieces presumably
being more easily seen because of their size), could result in higher rates
of entanglement and mortality.

If, as indicated by field observations (Fowler 1988; DeLong et
al. 1990), entanglement involves both sexes (especially among the
younger age classes), entanglement and resultant mortality may have
contributed significantly to the declining trends among fur seal
populations (Fowler 1985, 1988). Such implications are consistent
with recently observed population trends, and models consistent with
such trends have been constructed (Swartzman 1984; French and Reed
1990; Swartzman et al. 1990). These observations emphasize the need
for better studies to clarify our estimates of the degree to which
entanglement has caused these trends. Feasible field studies to
verify the role of entanglement in large debris have yet to be
designed and conducted.

CONCLUSIONS

The 1988 results of field research on entanglement of northern fur
seals through roundups of juvenile males on St. Paul Island, Alaska,
showed:

1. A reduction of the proportions observed entangled on land
    from about 0.4 to 0.29%.

2. Entanglement in fragments of trawl webbing in 1988 was about
    half of entanglement levels observed for this kind of debris
    in previous years.

3. The rate of resighting for animals tagged in 1985 and 1986
    and resighted in 1988 showed that entangled animals tagged
    in those years were seen at rates that were significantly
    less than the rate at which controls were resighted.

4. The pelagic portion of the feeding cycle of entangled seals
    is greater (and a larger portion of their time may be spent
    at sea) than that of control seals, but the extent of the
    difference is unknown.

Analysis of these data in combination with data from previous studies
(data on resighted animals collected in 1986, also on St. Paul Island, and
data on debris collected from 1967 through 1988) showed that:

5. The estimated survival due to being entangled in light
    debris ranged from 0.41 to 0.49, close to estimates of about
    0.5 or less from previous work.

6. Combined with natural survival, the total survival of
    entangled seals is probably <0.39, with the equivalent of
    nearly a complete turnover in the population of juvenile
    males entangled in light debris each year.

7. Mortality increases with the size of entangling debris based on the observation that survival for seals entangled in large debris is less than for those in small debris.

8. The probability of resighting entangled seals (or seals that once were entangled), compared to that of nonentangled seals, has yet to be clearly evaluated.

9. A great deal has been learned about the specifics of mortality caused by entanglement in debris weighing <500 g. Implications for effects at the general population level are serious. However, the main result of this progress is a continuing emphasis on the need to refine estimated mortality rates caused by large debris, especially pieces much larger than 500 g.

10. More studies will be required to better understand the interacting factors associated with the probability of entangled seals being resighted in the roundups.

ACKNOWLEDGMENTS

REFERENCES

Bengtson, J. L., C. W. Fowler, H. Kajimura, R. Merrick, K. Yoshida, and S. Nomura.
1988. Fur seal entanglement studies: Juvenile males and newly-weaned pups, St. Paul Island, Alaska. In P. Kozloff and H. Kajimura (editors), Fur seal investigations, 1985, p. 34-57. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-146.

Bengtson, J. L., B. S. Stewart, L. M. Ferm, and R. L. DeLong.
1989. The influence of entanglement in marine debris on the diving behavior of subadult male northern fur seals. In H. Kajimura (editor), Fur seal investigations, 1986, p. 48-56. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-174.

Brownie, C., D. R. Anderson, K. P. Burnham, and D. S. Robson.
1978. Statistical inference from band recovery data--a handbook. U.S. Fish Wildl. Serv., Resour. Publ. 131, 212 p.

DeLong, R. L., P. Dawson, and P. J. Gearin.
    1988. Incidence and impact of entanglement in netting debris on
    northern fur seal pups and adult females, St. Paul Island, Alaska.
    In P. Kozloff and H. Kajimura (editors), Fur seal investigations,
    1985, p. 58-68. U.S. Dep. Commer., NOAA Tech. Memo.-NMFS-F/NWC-146.

DeLong, R. L., P. J. Gearin, J. L. Bengtson, P. Dawson, and S. D.
    Feldkamp.
    1990. Studies of the effects of entanglement on individual northern
    fur seals. [Abstract.] *In* R. S. Shomura and M. L. Godfrey
    (editors), Proceedings of the Second International Conference on
    Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer.,
    NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. [See this document.]

Fowler, C. W.
    1982. Interactions of northern fur seals and commercial fisheries.
    Trans. N. Am. Wildl. Nat. Resour. Conf. 47:278-292.

    1985. An evaluation of the role of entanglement in the population
    dynamics of northern fur seals on the Pribilof Islands. *In* R. S.
    Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on
    the Fate and Impact of Marine Debris, 26-29 November 1984,
    Honolulu, Hawaii, p. 291-307. U.S. Dep. Commer., NOAA Tech. Memo.
    NMFS, NOAA-TM-NMFS-SWFC-54.

    1987. Marine debris and northern fur seals: A case study. Mar.
    Pollut. Bull. 18:326-335.

    1988. A review of seal and sea lion entanglement in marine fishing
    debris. *In* D. L. Alverson and J. A. June (editors), Proceedings of
    the North Pacific Rim Fisherman's Conference on Marine Debris,
    Kailua-Kona, Hawaii, 13-16 October 1987, p. 16-63. Unpublished
    report by Natural Resources Consultants, 4055 21st Avenue W.,
    Seattle, WA 98199.

Fowler, C. W., R. Merrick, and N. Baba.
    1989. Entanglement studies, St. Paul Island, 1988; juvenile male
    roundups. Northwest and Alaska Fish. Cent., Natl. Mar. Mammal
    Lab., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98115. NWAFC
    Processed Rep. 89-01, 23 p.

French, D., and M. Reed.
    1990. Potential impact of entanglement in marine debris on the
    population dynamics of the northern fur seal, *Callorhinus ursinus*.
    In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the
    Second International Conference on Marine Debris, 2-7 April 1989,
    Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-
    TM-NMFS-SWFSC-154. [See this document.]

Gentry, R. L., and J. R. Holt.
    1982. Equipment and techniques for handling northern fur seals.
        U.S. Dep. Commer., NOAA Tech. Rep. NMFS-SSRF-758, 15 p. (Available
        D822, User Serv. Br. Environ. Sci. Inf. Cent., NOAA, Rockville,
        MD.)

Lander, R. H.
    1981. A life table and biomass estimate for Alaskan fur seals.
        Fish. Res. (Amst.) 1:55-70.

Loughlin, T. R., J. L. Bengtson, and R. L. Merrick.
    1987. Characteristics of feeding trips of female northern fur seals.
        Can. J. Zool. 65:2079-2084.

Scordino, J.
    1985. Studies on fur seal entanglement, 1981-84, St. Paul Island,
        Alaska. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings
        of the Workshop on the Fate and Impact of Marine Debris, 26-29
        November 1984, Honolulu, Hawaii, p. 278-290. U.S. Dep. Commer.,
        NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Seber, G. A. F.
    1973. The estimation of animal abundance. Griffin, Lond., 506 p.

Swartzman, G. L.
    1984. Factors bearing on the present status and future of the
        eastern Bering Sea fur seal population with special emphasis on the
        effect of terminating the subadult male harvest on St. Paul Island.
        U.S. Marine Mammal Commission Report No. MMC-83/03. [Available
        from U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA
        22161, as No. PB84-172329, 77 p.]

Swartzman, G. L., C. A. Ribic, and C. P. Huang.
    1990. Marine debris entanglement mortality and fur seal populations:
        A modeling perspective. *In* R. S. Shomura and M. L. Godfrey
        (editors), Proceedings of the Second International Conference on
        Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep.
        Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. [See this
        document.]

APPENDIX

ESTIMATION OF ENTANGLEMENT-RELATED SURVIVAL AND THE RELATIVE PROBABILITIES OF ENTANGLED AND CONTROL FUR SEALS BEING RESIGHTED

To make use of the data on the returns of male fur seals (i.e., those resighted) as shown in Table 1, we make a set of assumptions and define the following terms. Let

$N_{c,ik}$ — the number of control seals tagged in year i and resighted in year k, where k > i (i – 1985,1986, k – 1986,1988).

$N_{e,ik}$ — the number of seals tagged in year i as entangled animals and resighted in year k (regardless of whether or not they were entangled when resighted), where k > i (i – 1985,1986, k – 1986,1988).

$P_{i,k}$ – $N_{e,ik}/N_{c,ik}$, or the ratio of numbers of seals resighted in year k that were entangled when first tagged in year i to the numbers of nonentangled (control) seals tagged in year i and resighted in year k.

$s_{c,j}$ — the annual survival of control animals, or the animals tagged without debris in year j, for j from i to k (i.e., $s_{c,j}$ – survival from j to j+1). This is the probability of surviving from natural causes of mortality.

s_e — the annual survival of animals entangled in light debris (debris light enough to return to the breeding islands), and is assumed not to vary from year to year. This is the probability of surviving entanglement given that an animal has survived natural causes of mortality and is assumed to be independent of $s_{c,j}$ (so their total annual survival is $s_{c,j}s_e$).

$N_{e,i}$ — the number of seals tagged as entangled animals in year i (i – 1985, 1986), and

$N_{c,i}$ — the number of seals tagged as controls in year i (i – 1985, 1986).

Different proportions of entangled seals may return to the islands to be seen when compared to controls. Once in the vicinity of the islands, entangled seals may be seen at different rates than the controls for various reasons. These include the possibility of different fractions of time spent on land and entangled seals being seen more readily than controls because of their entanglement, or the effects of having been entangled. Thus we define

f_{ek} — the probability of resighting a seal in year k given that it was entangled when tagged and that it is alive. This

probability is expressed on the basis of a unit of searching effort that is the same as applied in looking for control animals. It is assumed to vary from year to year but not in relation to f_{ck} (below), and

f_{ck} — the probability of resighting a control animal in year k given that it is alive in the population, again as based on the unit of effort spent in searching for both control and entangled seals. This is also assumed to vary from year to year but not in relation to f_{ek} (f_{ek}/f_{ck} is assumed constant).

With these terms, the expected number of seals that were entangled when tagged and sighted in year k after being tagged in year i, for one unit of effort is

$$E(N_{e,ik}|N_{e,i}) = f_{ek} \beta_k s_e^{(k-i)} N_{e,i}$$

(i = 1985,1986, k = 1986,1988, and β_k is the product of $s_{c,j}$ for j from i to k), and the expected number of controls for the same circumstances is

$$E(N_{c,ik}|N_{c,i}) = f_{ck} \beta_k N_{c,i}$$

(β_k is the product of $s_{c,j}$ for j from i to k).

Substituting the observed for the expected values we have the following moment estimators:

$$N_{e,ik} = f_{ek} \beta_k s_e^{(k-i)} N_{e,i} \quad \text{and} \quad N_{c,ik} = f_{ck} \beta_k N_{c,i}.$$

The ratio of these two equations, then, is

$$N_{e,ik}/N_{c,ik} = p_{i,k} = (f_{ek}/f_{ck})(N_{e,i}/N_{c,i}) s_e^{(k-i)}$$

which can be used to estimate f_{ek}/f_{ck} and s_e.

We note that variability in natural survival (i.e., the survival of the controls and that part of the survival of entangled animals from natural effects) can occur over time and not affect the calculation since these terms cancel in the formulation of the equation above. We also note that the probability of resighting animals from each of the two groups can vary from year to year as long as their ratio remains the same, as assumed above. Effort spent in resighting entangled and control seals is the same (the same roundups) but the number of roundups can vary from year. This is because effort for each of the two groups influences the above relationships only as a ratio in f_{ek}/f_{ck} (i.e., it cancels and need not be defined).

By rearranging terms we have

$$p_{i,k}(N_{c,i}/N_{e,i}) = (f_{ek}/f_{ck}) s_e^{(k-i)},$$

and taking the natural log of this equation results in the following linear equation which can be used for regression analysis and the estimation of relevant parameters as defined above:

$$\ln[p_{i,k}(N_{c,i}/N_{\bullet,i})] \;=\; \ln(f_{\bullet k}/f_{ck}) \;+\; \ln(s_{\bullet})(k-i).$$

Using this equation and the data from Table 6, the estimated parameters determined from regression analysis for the above equation are

$$\ln(f_{\bullet k}/f_{ck}) \;=\; 0.307 \text{ and } \ln(s_{\bullet}) \;=\; -0.720 \;(R^2 = 1.00, \; p = 0.011).$$

These results imply that the ratio of the probabilities of being resighted is about 1.35 (calculated as $e^{0.307}$, with 95% confidence limits of 0.95 to 1.95). Thus, the chances of being resighted after being tagged as an entangled animal, given that the animal has survived, are estimated to be about 1.35 times that of being resighted as a control, but this does not differ significantly from 1 or an equal probability. The estimated survival of entangled animals from the effects of entanglement is 0.49 (calculated as $e^{-0.720}$ with 95% confidence limits of 0.41 to 0.57).

In addition to the small sample size, other factors prevalent in this analysis need noting. The data points for the 1- and 3-year time intervals are not independent. A random difference between the mean (here assumed constant) survival from entanglement in the first year will be seen as a bias in the same direction in the third. With this set of data, this does not affect the estimate of entanglement-related survival as much as it does the estimated ratio of probabilities of being resighted. This is because the slope of the line as seen in Figure 2 (the estimate of survival) depends more on a rotation about the point for the 2-year time interval than the distance the line is above or below the second point. The height of the line will be affected by the interdependence of the two end points.

The effect of assuming that the survival from risks caused by entanglement is independent from surviving the risks of other, natural, causes has not been explored. The same holds for the assumption that the ratio of the probabilities of being resighted for the two categories remains the same over time. However the various steps in the derivation of the linear equation used in this analysis might contain hidden assumptions, or sources of statistical error, have yet to be examined.

A STUDY OF THE EFFECTS OF COMMERCIAL FISHING DEBRIS ON *CALLORHINUS URSINUS* FROM BREEDING ISLANDS IN THE WESTERN PACIFIC

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ABSTRACT

In this paper, data and analyses are presented concerning the incidence of entanglement among the northern fur seal, *Callorhinus ursinus*, from the breeding islands of the western Pacific. This work was undertaken to further explore the degree to which waste disposed from fishing vessels is a source of mortality for this species. Based on the available data, estimates of the minimum proportion of various age and sex groups entangled within the population are produced. Historical data show that injuries caused by fishing nets shreds (66%), ropes (20%), fishing line (8%), and packing bands and collars made of other materials (6%) are contributing to the mortality of northern fur seals. The incidence of entanglement, and therefore the resulting mortality among the Tyuleniy (Robben) Island population, is higher than for the population on the Komandorskie (Commander) Islands. The higher incidence of entanglement on Robben Island may be related to declines in the population on that island in comparison to the relative stability on the Commander Islands, where the incidence of entanglement is less.

BACKGROUND

The intensity of exploitation of living marine resources increases annually (Moiseev 1979). The number of fishing fleets increases correspondingly (Yerukhimovich and Yefremenko 1985). Increasing intensity in fishing brings with it various negative effects on the environment. One of the aspects of this influence is the pollution of the ocean with scraps of fishing gear, packing materials, and other waste from the commercial fisheries, directly threatening many marine organisms. Fish, seabirds, reptiles, and marine mammals get entangled in such materials and die (DeGange and Newby 1980; Fowler 1982, 1985, 1987; Kuzin 1985; Shomura and Yoshida 1985).

A determination of the extent of the negative influence of commercial fishing waste and pollution in the ocean is not possible for the majority of marine organisms. But the continuous and systematic observation of

northern fur seals, returning each year to their hauling grounds (near the breeding colonies) after wintering in the ocean, provides the opportunity to determine the number of individuals entangled in marine debris. The resulting data allow for the calculation of estimates of the extent of damage caused by marine debris resulting from loss and discard by commercial fisheries as well as other human activities.

From the historical data, the kinds of debris found on entangled seals is known. Of the total number of entangled seals on Robben Island, 66% are entangled in fragments of fishing nets. Another 20% are found entangled in ropes, 8% in fishing line, and 6% in packing bands and collars made of other materials of commercial fishing waste (Kuzin 1985). Fowler's data (1982) showed that in the Pribilof Island population as many as 50,000 seals may die annually as a result of injuries caused by foreign objects. Over a life time, entanglement may cause the death of 15% of a cohort (Fowler et al. 1990). Similar estimates for other populations of fur seals, however, are unavailable.

In order to obtain estimates of entanglement-related mortality for populations of fur seals on both Robben and the Commander Islands, the statistical data presented annually to the Northern Pacific Fur Seal Commission regarding the incidence of entanglement among northern fur seals on hauling grounds are used.

METHODS

For estimating the effects of commercial fishing debris on fur seal populations, we have used the data from the commercial harvest of bachelor seals (2- to 5-year-old males, also referred to here as juvenile males). These data were collected by counting the total and the number of entangled male seals in the commercial harvest for each year from 1975 to 1986 on both Robben Island and the Commander Islands (Table 1). All entangled seals were of the same size category as the remaining seals taken in the harvest. These harvests were conducted during the months of June and July of each year, and all entangled seals were killed along with the other seals taken. Seals with scars only were not counted as entangled such that the counts included only male seals observed with entangling debris. Entangling debris found on the seals was then identified and frequencies were tabulated for each category of debris. Pieces of monofilament gillnet were included in the category of net shreds along with pieces of trawl net debris.

With the data on total numbers taken in the harvest and the counts of entangled seals among them, collected as described above, the incidence of entangled animals among the juvenile males (2 to 5 years old) was determined by dividing the number of entangled seals taken by the total in the harvest for each year and location.

For other age groups and sex groups of seals, data are not available from their primary concentrations on the breeding rookeries. However, data have been recorded for entangled individuals from these categories, as noted for seals found on hauling grounds. Thus, the percent of all entangled animals found on hauling grounds that fall into each category

Table 1.--Number of juvenile male fur seals taken and the
incidence of seals entangled in debris in the commercial
harvest by year and location (breeding islands in the
western Pacific).

Year	Number harvested		Number entangled		Percent entangled	
	Robben	Commander	Robben	Commander	Robben	Commander
1975	2,500	1,730	27	30	1.08	1.73
1976	2,569	2,768	69	68	2.68	2.46
1977	4,069	2,766	69	66	1.69	2.39
1978	3,188	3,032	81	32	2.54	1.06
1979	2,933	2,524	33	13	1.13	0.52
1980	3,107	2,544	26	44	0.83	1.73
1981	3,613	5,117	113	35	3.12	0.76
1982	2,924	5,075	124	75	4.20	1.48
1983	2,582	5,717	24	34	0.92	0.59
1984	2,322	5,294	35	37	1.50	0.70
1985	459	5,097	4	47	0.87	0.92
1986	2,034	--	34	--	1.67	--
Total	32,300	41,664	639	481	1.97	1.15

can be determined. The categories used in this study are: mature males
(older than 6 years), half-mature males (or "half bulls," 6 years of
age), bachelors (younger than 6 years), females, and pups. Since exact
ages are not known, the numbers in each age category are determined on
the basis of experienced judgment.

To analyze the data resulting from the field work described above, a
method for estimating lower bounds of the proportion of each age-sex class
was developed. The following is an explanation of the procedure used.

As mentioned above, the empirical data are for a population consisting
of several categories or age-sex groups. One category is represented by
data for which the incidence of entanglement can be clearly determined
(i.e., the bachelor males, which will be represented by subscript j). The
other groups (e.g., pups, females) are those for which we wish to have
estimates of the incidence of entanglement. These groups will be repre-
sented by subscript i.

To develop a procedure for estimating the proportion of seals
entangled in each group, their total numbers in the population as a whole
are defined as P_i. The total for the bachelor males is defined as P_j. The
proportion entangled (or incidence of entanglement) is defined as C_i and
C_j, respectively, for each of the two categories, so that the numbers
entangled are $C_i P_i$ and $C_j P_j$. Of these, a proportion of each category is
seen, a proportion defined as α (α_i and α_j, respectively) so that the
actual numbers of entangled animals seen on land are $\alpha_i C_i P_i$ and $\alpha_j C_j P_j$ for

the two cases. It is assumed that the probability of seeing an entangled animal of any category is the same as the probability of seeing a nonentangled animal of the same category or that entanglement does not influence the probability of being seen. This may be summarized as follows:

Category	Total population	Fraction entangled	Numbers entangled	Proportion seen	Entangled animals seen
i	P_i	C_i	$C_i P_i$	α_i	$\alpha_i C_i P_i$
j	P_j	C_j	$C_j P_j$	α_j	$\alpha_j C_j P_j$

The desired estimate is of C_i, knowing C_j. This can be accomplished by dividing the number of entangled animals seen from category i ($\alpha_i C_i P_i$, for which there are data) by the number of animals seen in category j ($\alpha_j C_j P_j$, also for which there are data) and multiplying this ratio by $C_j(\alpha_j P_j / \alpha_i P_i)$:

$$(\alpha_i C_i P_i / \alpha_j C_j P_j) \; C_j \; (\alpha_j P_j / \alpha_i P_i) \; = \; C_i$$

For this equation to produce the correct estimate (disregarding the statistical aspects of the problem), then, it is seen that either values for $\alpha_i P_i$ and $\alpha_j P_j$ must be known (which they are not) or their ratio must be known. If this ratio were 1.0, the number of the two segments seen would be equal.

Based on observations on hauling grounds, the total number of seals in the bachelor category is always larger than the total for each of the other categories listed in Tables 2 and 3. (Here we refer to the total present, not the number of entangled seals seen.) Because of this, the equation above can be used by assuming $(\alpha_j P_j / \alpha_i P_i) > 1.0$ to determine lower bounds to the entanglement rates for the categories other than for bachelors. The value of the expression $(\alpha_j P_j / \alpha_i P_i)$ will always be greater than 1.0 since $\alpha_j P_j$ (the number of bachelor males seen on hauling grounds) is always greater than the number seen for other groups. Thus, the expression used to produce estimated lower bounds for the proportion entangled for groups other than bachelor males is:

$$C_i > N_i C_j / N_j$$

where:

C_i is the proportion of animals of the age-sex group in question that are entangled;

$N_i = \alpha_i C_i P_i$ is the number of entangled animals of the age-sex group in question as observed at the hauling grounds;

C_j is the proportion of bachelors that are entangled; and

$N_j = \alpha_j C_j P_j$ is the number of entangled bachelors observed at the hauling grounds.

Table 2.--Number and percent of entangled fur seals falling in
various age and sex categories as observed at hauling grounds
on Robben Island.

	Bulls		Half bulls		Bachelors		Females		Pups		Total	
Year	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1974	4	1.5	10	3.8	115	43.4	136	51.3	--	--	265	100
1975	--	--	--	--	27	77.1	8	22.9	--	--	35	100
1976	2	2.2	1	1.1	69	71.2	21	22.6	--	--	93	100
1977	2	2.8	--	--	69	97.2	--	--	--	--	71	100
1978	53	18.0	47	15.9	58	19.7	135	49.9	1	0.3	294	100
1979	16	19.2	9	10.8	16	19.3	42	50.6	--	--	83	100
1980	1	0.8	4	3.5	102	88.7	8	6.9	--	--	115	100
1981	11	15.7	5	7.1	19	21.1	32	45.7	3	4.3	70	100
1982	4	3.2	5	4.3	65	52.4	50	40.3	--	--	124	100
1983	12	12.4	--	--	13	13.4	72	74.2	--	--	97	100
1984	16	18.4	5	5.7	18	20.7	47	54.0	1	1.1	87	100
1985	10	10.8	--	--	31	30.0	61	59.8	--	--	102	100
1986	5	6.8	2	2.4	19	22.9	53	63.9	4	4.8	83	100
1987	10	13.5	8	10.8	13	17.5	43	58.1	--	--	74	100
Total	146	9.2	96	6.0	634	39.8	708	44.4	9	0.6	1,593	100

Calculated minimum percent of entangled individuals:

	0.45		0.30		[a]1.97		2.19		0.03			

[a]From Table 1.

RESULTS

The numbers of seals taken in the commercial harvests on Robben Island
and the Commander Islands, and the numbers of entangled seals among them are
shown in Table 1 for 1975 through 1986. Also shown is the resulting
incidence of entanglement expressed as a percent of the harvest. The
number of entangled seals from the other categories, as observed on the
hauling grounds, are shown in Table 2 for Robben Island, and Table 3 for
the Commander Islands. Tables 2 and 3 also show the fraction of the total
number of entangled animals observed as accounted for by seals in each
category. Thus, the totals of the categories are each 100% for all
observed entanglement, by year and island.

The results of calculations to determine the lower bounds to estimates
of the percent entangled among each age-sex group of northern fur seals are
presented in the last lines of Tables 2 and 3. The proportion of the total
population which is entangled depends on the fraction of the population
comprised by each of the age-sex categories. However, it can be seen that
the lower bound for the overall entanglement rate must be between 0.03 and

Table 3.--Number and percent of entangled fur seals falling in various age and sex categories as observed at hauling grounds on the Commander Island.

Year	Bulls No.	Bulls %	Half bulls No.	Half bulls %	Bachelors No.	Bachelors %	Females No.	Females %	Pups No.	Pups %	Total No.	Total %
1974	--	--	--	--	--	--	--	--	--	--	--	--
1975	1	2.9	2	5.7	13	34.1	19	54.3	--	--	35	100
1976	--	--	--	--	--	--	--	--	--	--	--	--
1977	8	9.4	11	12.9	25	29.4	30	35.3	11	12.9	85	100
1978	--	--	--	--	--	--	--	--	--	--	--	--
1979	63	26.8	2	2.0	126	53.6	41	17.4	5	2.1	237	100
1980	26	24.1	--	--	40	37.0	39	36.1	3	2.8	108	100
1981	21	15.9	7	5.3	85	64.4	19	14.4	--	--	132	100
1982	17	12.2	16	11.5	81	58.3	25	17.9	--	--	139	100
1983	36	39.1	5	5.4	20	21.7	31	33.7	--	--	92	100
1984	--	--	--	--	--	--	--	--	--	--	--	--
1985	--	--	--	--	--	--	--	--	--	--	--	--
1986	13	27.7	3	6.4	21	44.6	10	21.3	--	--	47	100
1987	--	--	--	--	--	--	--	--	--	--	--	--
Total	185	21.1	46	5.3	411	46.9	214	24.5	19	2.21	875	100

Calculated minimum percent of entangled individuals:

0.52	0.13	[a]1.15	0.59	0.05

[a]From Table 1.

2.19% for Robben Island and between 0.05 and 1.15% for the Commander Islands. These estimated lower bounds cover the period from June through August (3 months), the time during which seals are seen on the hauling grounds.

DISCUSSION

It is natural that some seals that are entangled in commercial fishing waste die at sea without being seen on land, especially in the areas where seals from the western Pacific overwinter (Pacific Ocean and Sea of Japan in the Japanese, Korean, and American exclusive economic zones). However, data concerning entanglement rates and mortality for these areas are not available. In Fowler's (1985, 1987) work and Fowler et al. (1990), information is presented as a basis for accounting for unseen mortality at sea. After accounting for debris that is too large for seals to return to land, mesh sizes that pups become entangled in, and the mortality rates observed in large debris, as many as 30 to 35 seals per year may die for each one that is observed alive. The effects of the size composition of debris at sea has not been considered in its effects on seal populations of the

western Pacific. Neither have the effects of mesh size. However, in view of the levels of entanglement presented in Tables 2 and 3, it is clear that an even lower ratio of unseen mortalities to observed entanglement would be necessary to achieve similar levels of mortality thought possible for the Pribilof population. Further data on the size composition (by weight and mesh) of debris from beaches and pelagic habitat in the western Pacific will be necessary to extend this evaluation of the potential effects of marine debris on the mortality of fur seals.

There is a very important observation to be noted in the data in Tables 2 and 3, an observation that deserves to be emphasized. At the Commander Islands, the incidence of entanglement among seals is lower than at Robben Island. Among bachelors, the incidence of entanglement is 1.7 times as high on Robben Island as on the Commander Islands. The minimum level of entanglement for females is almost four times as high. The importance of this observation comes from the fact that this may be one of the reasons why the Commander Island seal population did not decrease in recent years, while other populations declined. This emphasizes the need for further information on the composition of debris (by weight and mesh size) to determine if there are differences between the western and eastern Pacific. Such differences might explain the divergence in dynamics between the population of fur seals on the Commander Islands (no recent declines) and the Pribilof Islands (a decline in the late 1970's).

If mortality due to entanglement is as high in the western Pacific as is thought possible for the Pribilof population, as many as 3.7 to 6.7 thousand seals die from entanglement annually. In the North Pacific as a whole, then, as many as 60,000-65,000 northern fur seals may die due to the discard and loss of gear and debris from commercial fisheries. Those figures are 1.7-2 times higher than the figures of the potential annual harvest of juvenile male northern fur seals in the U.S.S.R. and the United States.

It is known that 60% of the Robben Island seals, 5-6% of the Pribilof seals, and 28-30% of the Commander Island seals winter in Japanese waters (Ashchepkov and Kuzin 1986). Cooperative efforts involving all interested countries seem necessary for studying the problem of the pollution of the ocean by commercial fishing waste. The existing fisheries-oriented scientific associations among the Pacific countries provide the opportunity for their leadership to inform fisheries organizations about the sources of debris and the volume of the damage caused by commercial fishing to marine resources. The solving of this problem depends on how soon and how completely sailors and fishermen realize the seriousness of marine pollution and that the discard of debris is contrary to international regulations.

REFERENCES

Ashchepkov, A. T., and A. E. Kuzin.
  1986. Abundance and age-sex composition dynamics of the different reproductive seal groups at wintering places in Sea of Japan and off the Japanese Pacific coast. Izuchenie, okhrana i ratsionalnoe ispolzovanie morskikh mlekopitayushchikh. Archangel. 14-16. [In Russ.]

DeGange, A. R., and T. C. Newby.
    1980. Mortality of seabirds and fish in a lost salmon driftnet.
    Mar. Pollut. Bull. 11:322-323.

Fowler, C. W.
    1982. Interactions of northern fur seals and commercial fisheries.
    Trans. N. Am. Wildl. Natur. Resour. Conf. 47:278-292.

    1985. An evaluation of the role of entanglement in the population
    dynamics of northern fur seals on the Pribilof Islands. *In* R. S.
    Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on
    the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu,
    Hawaii, p. 291-307. U.S. Dep. Commer., NOAA Tech. Memo. NMFS,
    NOAA-TM-NMFS-SWFC-54.

    1987. Marine debris and northern fur seals: A case study. Mar.
    Pollut. Bull. 18:326-335.

Fowler, C. W., R. Merrick, and J. D. Baker.
    1990. Studies of the population level effects of entanglement on
    northern fur seals. *In* R. S. Shomura and M. L. Godfrey (editors),
    Proceedings of the Second International Conference on Marine Debris,
    2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech.
    Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. [See this document.]

Kuzin, A. E.
    1985. Injuring of fur seals with the commercial fishing waste in the
    northern Pacific. Issledovanie i ratsionalnoe ispolzovanie
    bioresursov dalnevostochnykh i severnykh morey. Tez. Vses. Soveshch.
    Valdivostok, p. 92-93. [In Russ.]

Moiseev, P. A.
    1979. Biological resources of the ocean. *In* Biologicheskie resursy
    mirovogo okeana, p. 13-26. Nauka Publ., Moscow. [In Russ.]

Shomura, R. S., and H. O. Yoshida (editors).
    1985. Proceedings of the Workshop on the Fate and Impact of Marine
    Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer.,
    NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54, 580 p.

Yerukhimovich, V. B., and S. K. Yefremenko.
    1985. Tasks of the fisheries science in relation to the far-eastern
    fisheries development. *In* Problemy dalnevostochnoy
    rybokhozyaystvennoy nauki, p. 122-136. Agropromizdat Publ., Moscow.
    [In Russ.]

AN INDEX OF FUR SEAL ENTANGLEMENT IN FLOATING NET FRAGMENTS

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ABSTRACT

While information has been published on transect surveys
based on visual sighting of floating marine debris, few attempts
have been made to link the estimates of floating marine debris
density to the entanglement rate observed in subadult male fur
seals. Both published and unpublished survey data were used to
develop a data base consisting of the location and season during
which floating marine debris were observed and the estimated
density of the debris. In conjunction with this data base,
similar information was used for at-sea sightings of fur seals
to calculate an index of potential entanglement by season
(winter and breeding season, spring and fall migration). Our
main conclusion is that much more information is needed to cover
the known range of migrating northern fur seals. However, with
these limited data, it appears that seals are most at risk
during the breeding season and during the fall migration. Our
conclusions are tentative due to assumptions used in calculating
the index and the lack of geographical overlap between oceanic
debris surveys and fur seal surveys.

INTRODUCTION

The fact of entanglement and the problems it may cause animals is not
an area of debate (Center for Environmental Education 1986). But the role
of entanglement in contributing to the recent decline of the northern fur
seal, *Callorhinus ursinus*, on the Pribilof Islands remains to be clearly

defined (Fowler 1985, 1987; Scordino 1985). We (Swartzman et al. 1990) have taken a modeling approach to this problem, but the model is only as good as the estimates of the parameters and their inherent variability. In this paper, we calculate an index of potential entanglement by using information on floating marine debris and at-sea locations of fur seals. Problems with this approach are discussed.

METHODS

A review of all papers dealing with floating marine debris was used to gather information on the density of marine debris by area. All estimates from the papers were translated into number of net fragments per square nautical mile for comparison and mapped by area (using blocks of latitude and longitude as defined in the papers). We could not separate the nets into different types (trawl web or gillnet) because the data as presented in the papers were not separated by type. Unpublished data of Yoshida and Baba (Far Seas Fisheries Research Laboratory, pers. commun.) and the 1984 marine mammal observer program data (L. Jones, National Marine Mammal Laboratory, Seattle, WA, pers. commun.) were used to calculate additional density estimates by area. A strip transect density estimate (number of net fragments per square nautical mile) was calculated using a half width of 50 m (Dahlberg and Day 1985) and mapped.

For fur seal occurrence, the data in Kajimura (1980) were used. Those data are presented in summary form in terms of number of degree blocks where 0, 1-4, 5-8, or 9+ seals were seen per hour of observation for all surveys in 1958-74 by month. We calculated an index of high density of seals by 5 degree blocks from these data by month. The index of high density was chosen as the number of degree blocks with five or more seals sighted per hour of observation divided by the total number of degree blocks sampled. We calculated this index for four time periods: January-March, April-June, July-October, and November-December. These periods correspond to winter, spring migration, breeding season, and fall migration (Kajimura 1980), respectively. For each time period, the index of high density was the average of the indices for the months making up the particular period. The indices were mapped for each time period.

The two maps (debris density and fur seal occurrence) were put onto the same scale and superimposed, and areas of overlap identified by time period. Areas of no effort (indicated as blank spots on the maps) for either base set (debris or seals) automatically meant a blank spot for the combined set. For the areas of overlap, an index of potential entanglement was defined as the product of the estimated density of marine debris and the index of high fur seal density. Assumptions made because of the available data include:

- There are no age and sex differences for probability of fur seal occurrence. (Data were not divided into age and/or sex categories.)

- There have been no major changes in the pelagic distribution of fur seals. (Data were collected between 1958 and 1974.)

- Net density is constant over the seasons. (Data were not available on a seasonal basis.)

- The density and location of small and large net fragments are the same. (Data were not presented on a size basis, therefore, differences in probability of entanglement due to differences in size of net fragment cannot be factored into the index.)

- There are no seasonal changes in fragment-specific probability of entanglement. (No information was available on this point.)

The magnitude of the numbers was used to compare the relative probability of potential entanglement between areas within a time period and between time periods.

RESULTS

The papers with the most information on the density of floating nets were those by Jones and Ferrero (1985), Yoshida and Baba (1985), Baba et al. (1988), and Mio and Takehama (1988). Most of the information on floating marine debris has been collected in the North Pacific Ocean in the middle of the fishing fleets (Fig. 1). Most of the information on the presence of fur seals has been collected along the coast and in the Gulf of Alaska (Fig. 2). Fur seals have been seen offshore in the North Pacific Ocean (Kajimura 1980). However, since sighting effort is not recorded, these data cannot be used in a direct evaluation of the probability of entanglement. There are two areas where the maps overlap: around the Pribilof Islands and off the coasts of Washington and Oregon (Fig. 3).

Although there is little overlap between the two maps, for those areas where we could calculate an index of potential entanglement, the highest indices occurred during the breeding season (July-October) around the Pribilof Islands and in the fall migration (November and December) off the coasts of Washington and Oregon (Fig. 3). The index was also relatively high for some blocks off the coasts of Washington and Oregon for the winter season (January-March) and the spring migration (April-June) (Fig. 3).

DISCUSSION

The major problem in estimating the level of entanglement at sea is the lack of systematic observations of both fur seals and marine debris in the same area. The lack of data is so extreme as to present major problems in calculating indices of entanglement while seals are in their pelagic environment. As can be seen from this analysis, there was little overlap between the sets of data for the areas that were surveyed. In addition, for the existing data sets, the units for marine debris density and the probability of fur seal occurrence are not the same. There were no data for the effort behind the fur seal sightings. These circumstances lead to obvious problems in trying to use the existing empirical data to calculate
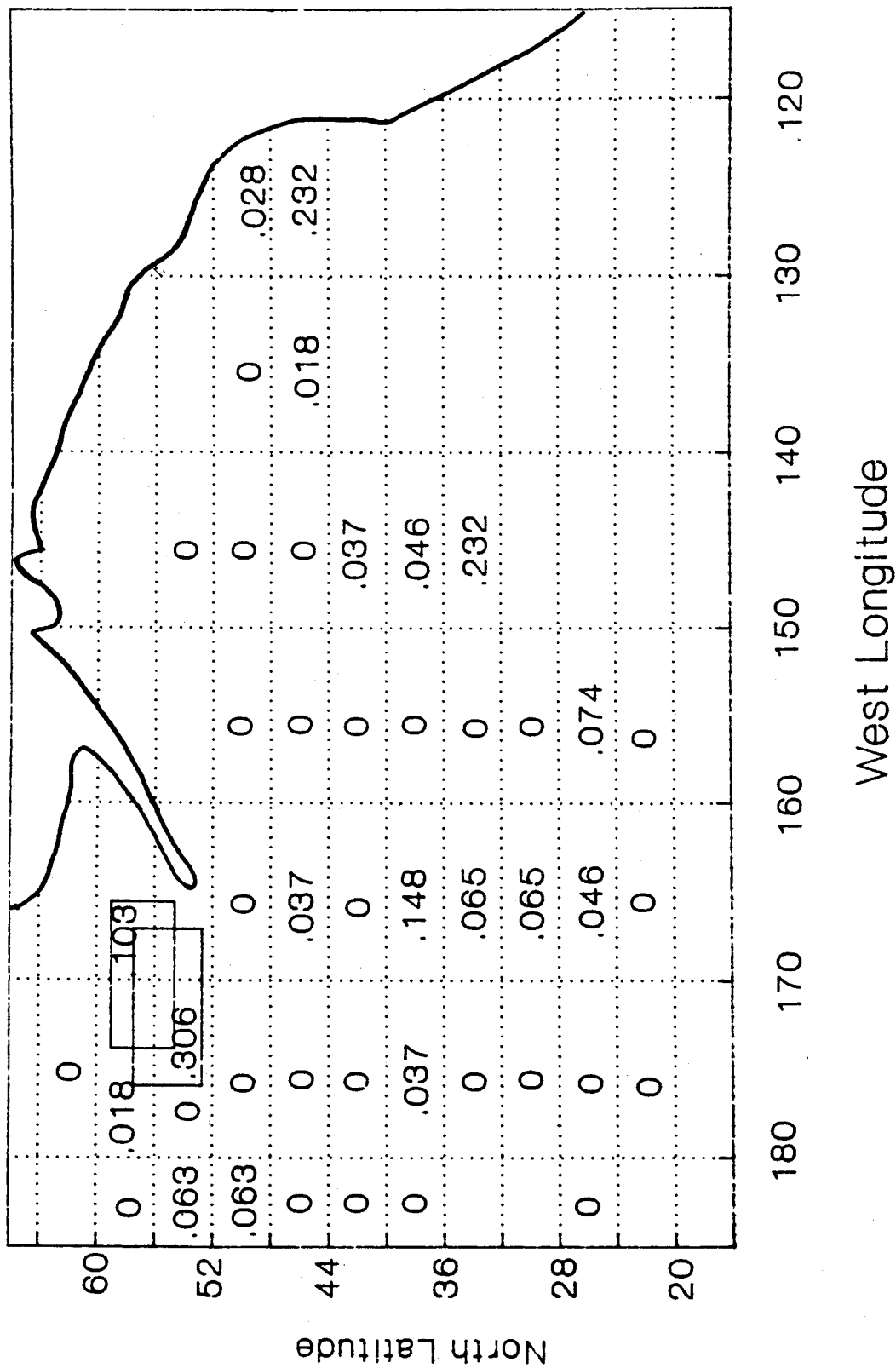
Figure 1.--Density of floating nets by blocks of 4° latitude and 10° longitude calculated from published and unpublished data. The two solid line rectangles indicate areas around the Pribilof Islands where densities were calculated for 2 separate years. The coastline is outlined in black.
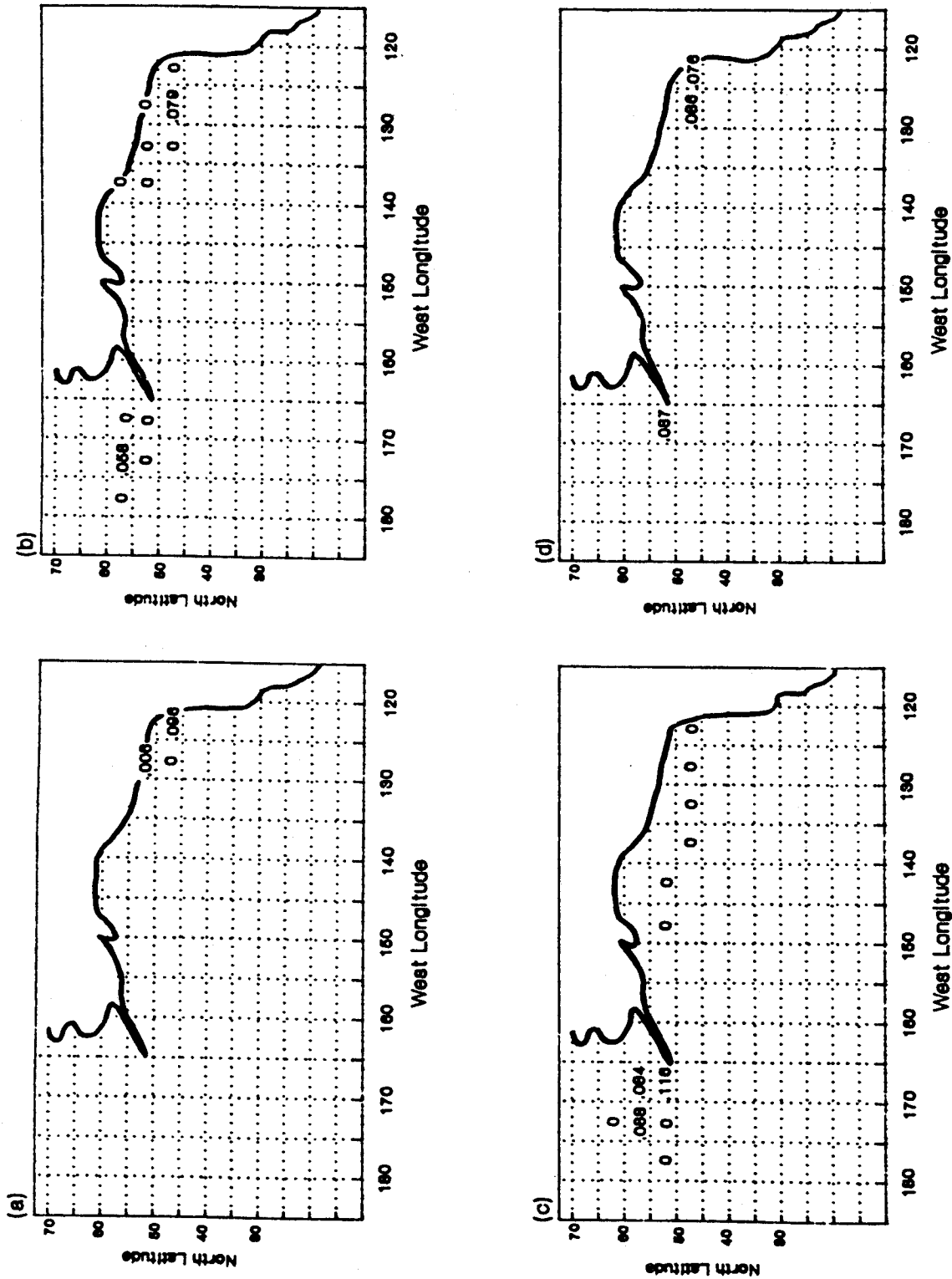
Figure 2.--Index of high fur seal density calculated from data in Kajimura (1980) for four time periods: (a) January-March, (b) April-June, (c) July-October, and (d) November-December. The coastline is outlined in black.

Figure 3.--Index of potential entanglement for common areas between Figures 1 and 2 for four time periods: (a) January-March, (b) April-June, (c) July-October, and (d) November-December. The coastline is outlined in black.

an index. What is needed is a study specifically designed and coordinated for three purposes. The first purpose would be to estimate the density and location of floating net fragments; the second would be to record the numbers and location of fur seals; and the third would be to collect information on the number of fur seals entangled in debris. All three parts of the study should consider the seasonal aspects of the distribution and abundance of both seals and debris. The data from such a study would have the debris and fur seal variables on the same scale (e.g., number per unit area) as well as contain information on the location and date of observed at-sea fur seal entanglement. Until such a study is done, combining results of other studies for such purposes will be highly speculative and will depend on a large number of assumptions, as evidenced by this study.

The assumptions used in this study were made to compensate for the lack of data on variables such as differences in location by age and sex for seals and differences in large and small net fragment densities and location. Changing an assumption will affect the value of the index, but whether the comparisons are changed will depend on how the assumption is changed. For example, if the probability of entanglement upon encounter changes with season, then the comparisons between seasons would be affected.

Given all the assumptions, the index calculated here indicates that the probability of potential entanglement may change depending on the season of year and, in a related fashion, on location. If the relatively high potential entanglement index around the Pribilof Islands found here is valid, then it may indicate that the entanglement problem begins as soon as the young of the year go to sea and continues as the animals migrate south for the winter. Since the first year after weaning is a stressful time for young animals, the actual impact of entanglement may be severe for fur seals going to sea for the first time.

ACKNOWLEDGMENTS

REFERENCES

Baba, N., K. Yoshida, M. Onoda, N. Nagai, and S. Toishi.
    1988. Results of research on floating fishing gear and fish net fragments in the area southwest of the Pribilof Islands and off southern coasts of the Aleutian Islands, July-August 1985. *In* D. L. Alverson and J. A. June (editors), Proceedings of the North Pacific Rim Fisherman's Conference on Marine Debris, Kailua-Kona, Hawaii, 13-16 October 1987, p. 143-164. Unpublished report by Natural Resources Consultants, 4055 21st Avenue W., Seattle, WA 98199.

Center for Environmental Education.
    1986. Marine wildlife entanglement in North America. Center for
        Environmental Education, Wash., D.C., 219 p.

Dahlberg, M. L., and R. H. Day.
    1985. Observations of man-made objects on the surface of the North
        Pacific Ocean. In R. S. Shomura and H. O. Yoshida (editors),
        Proceedings of the Workshop on the Fate and Impact of Marine
        Debris, 26-29 November 1984, Honolulu, Hawaii, p. 198-212. U.S.
        Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Fowler, C. W.
    1985. An evaluation of the role of entanglement in the population
        dynamics of northern fur seals on the Pribilof Islands. In R. S.
        Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on
        the Fate and Impact of Marine Debris, 26-29 November 1984,
        Honolulu, Hawaii, p. 291-307. U.S. Dep. Commer., NOAA Tech. Memo.
        NMFS, NOAA-TM-NMFS-SWFC-54.

    1987. Marine debris and northern fur seals: A case study. Mar.
        Pollut. Bull. 18:326-335.

Jones, L. L., and R. C. Ferrero.
    1985. Observations of net debris and associated entanglements in the
        North Pacific Ocean and Bering Sea, 1978-84. In R. S. Shomura and
        H. O. Yoshida (editors), Proceedings of the Workshop on the Fate
        and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii,
        p. 183-196. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-
        NMFS-SWFC-54.

Kajimura, H.
    1980. Distribution and migration of northern fur seals (Callorhinus
        ursinus) in the eastern Pacific. In H. Kajimura, R. H. Lander, M.
        A. Perez, A. E. York, and M. A. Bigg (editors), Further analysis of
        pelagic fur seal data collected by the United States and Canada
        during 1958-74, Part I, p. 6-50. Report submitted to the 23rd
        Annual Meeting of the Standing Scientific Committee, North Pacific
        Fur Seal Commission, 7-11 April 1980, Moscow, U.S.S.R.

Mio, S., and S. Takehama.
    1988. Estimation of distribution of marine debris based on the 1986
        sighting survey. In D. L. Alverson and J. A. June (editors),
        Proceedings of the North Pacific Rim Fisherman's Conference on
        Marine Debris, Kailua-Kona, Hawaii, 13-16 October 1987, p. 64-94.
        Unpublished report by Natural Resources Consultants, 4055 21st
        Avenue W., Seattle, WA 98199.

Scordino, J.
    1985. Studies on fur seal entanglement, 1981-84, St. Paul Island,
        Alaska. In R. S. Shomura and H. O. Yoshida (editors), Proceedings
        of the Workshop on the Fate and Impact of Marine Debris, 26-29
        November 1984, Honolulu, Hawaii, p. 278-290. U.S. Dep. Commer.,
        NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Swartzman, G. L., C. A. Ribic, and C. P. Huang.
    1990. Simulating the role of entanglement in northern fur seal,
    Callorhinus ursinus, population dynamics. *In* R. S. Shomura and M.
    L. Godfrey (editors), Proceedings of the Second International
    Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii.
    U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154.
    [See this document.]

Yoshida, K., and N. Baba.
    1985. Results of a survey on drifting fishing gear or fish net
    pieces in the Bering Sea. Document submitted to the 28th Meeting
    of the Standing Scientific Committee of the North Pacific Fur Seal
    Commission, 4-12 April 1985, Tokyo, 13 p.

STUDIES OF THE EFFECTS OF ENTANGLEMENT
ON INDIVIDUAL NORTHERN FUR SEALS

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ABSTRACT

During the field seasons of 1985 and 1986, studies were conducted to determine the effects of entanglement on the northern fur seal, *Callorhinus ursinus*. These included surveys of entanglement rates among pups and adult females, an experiment on the effects of entanglement on adult females, and a study of the selectivity of mesh size in the entanglement of pups. Complementing these studies are data on the history of the development of wounds for entangled juvenile males that have been seen more than one time.

In 1985, 40 parturient females and their pups were captured at Zapadni Reef rookery on St. Paul Island. Half of the females were treated as controls and tagged with both flipper tags and radio tags and released. Pieces of trawl net weighing 200 g were placed on the other 20, simulating entanglement common to fur seals. The attendance cycles and rates of return of these animals were then compared for the two groups for several feeding cycles, and the rates of return were compared the following season. Three of the entangled females freed themselves of the debris. Of the remaining 17, 3 failed to return after their first trip to sea, 4 failed to return after their second trip, and 2 did not return after their third trip. One control did not return after her second trip to sea. The time spent at sea by the entangled animals was twice as long as for the control animals. In 1986, 2 of the 17 entangled animals were observed, whereas 12 of the 20 controls were observed.

Ground surveys for females were conducted on rookeries chosen for ease of access to observe animals. Entangled females were counted during these surveys, and the counts were converted to entanglement rates by using the numbers of pups estimated for each of the rookeries as an indication of the number of females present. Rates calculated on this basis ranged from 0.06 to 0.23% for the sample rookeries with a mean of 0.15%. This is to be compared to the 0.4% seen for the juvenile males.

Between 11 September and 16 October 1986, 39 entangled pups were observed. Of these, five were in a single piece of trawl webbing that had become wrapped around a channel marker, and another five were in a piece of blue trawl webbing that washed ashore. As with other components of the population, trawl webbing comprised the highest portion of the entangling debris (19 out of the 39 observed). Entanglement rates for these animals are not known because we have no information on the portion of the pup population that had already departed for sea. The live entangled pups were tagged and released.

During 1985, experimental studies of pup entanglement showed that pups of the size of those found on the islands in October can become entangled in trawl debris with mesh sizes as small or smaller than 16 cm (stretched). All experimental pups placed in a tank with pieces of net with mesh sizes between 18 and 22 cm became entangled within 5 h or less. Some became entangled about their face in pieces with mesh sizes as small as 14 cm.

Data on the interannual history of a small number of entangled subadult males indicate that growth in body size and abrasion brought about by movement cause wounds to increase in size.

STUDIES OF THE EFFECTS OF NET FRAGMENT ENTANGLEMENT ON NORTHERN FUR SEALS
PART 1: DAILY ACTIVITY PATTERNS OF ENTANGLED AND NONENTANGLED FUR SEALS

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ABSTRACT

Effects of net fragment entanglement on the behavior of fur seals were examined using radio telemetry. Radio transmitters were attached to three fur seals 5-8 years old kept in an aquarium. Two of the seals were entangled with 1- and 2-kg fishing net fragments, respectively, around their necks. Using radio telemetry, their activity patterns were recorded for 36 days, from 28 January to 4 March 1985. The seal entangled with the 2-kg net showed the shortest active time per day and the nonentangled seal showed the longest. Active time of the entangled individuals increased after removal of the nets. It becamed clear that the active time of fur seals was diminished by entanglement in net fragments.

INTRODUCTION

It has been reported that some northern fur seal, *Callorhinus ursinus*, returning to breeding islands were entangled in marine debris such as fishing net fragments and packing bands (Scordino 1985). The fur seal population of the Pribilof Islands declined to less than half of its 1940's peak, and mortality due to entanglement is suspected as a major cause of the population decline (Fowler 1982). In what period and at what rate do entangled fur seals die? This issue was examined through tag and resighting surveys of entangled fur seals on St. Paul Island (Bengtson et al. 1988; Scordino et al. 1988). The survival period of entangled animals is considered to vary according to the damage caused by entanglement. There have been only a few reports about the effects of net fragments on fur seals (Feldkamp et al. 1987). This study was intended to examine the effects of entanglement on activity patterns of fur seals using radio telemetry.

MATERIALS AND METHODS

Experimental Fur Seals and Radio Equipment

The three female fur seals used in the experiment were captured off Joban coast, north Japan, between 4 and 9 March 1982, and had been kept in captivity for 3 years. The estimated ages of the animals were 5-8 years and body weights were 29.5-36.0 kg at the beginning of the experiment (Table 1). The experiment was conducted in an aquarium, Izu-Mito Sea Paradise, Numazu, central Japan, where the animals were kept.

A radio transmitter and trawl net fragments were attached to the seals on 28 January 1985. Of the three, one (referred to hereafter as N0) was loaded only with a transmitter. A transmitter and a 1-kg net fragment were attached to one of the remaining two (N1), and a transmitter and 2-kg net fragments to the other (N2). Trawl nets used in the experiments were those commonly used in commercial fishing; they were made of polyethylene with a twine size of 3.4 mm and a mesh size of 24 cm. The transmitter was cylindrical in shape, 35 mm in diameter, 155 mm long, and 200 g in atmospheric weight. It had a life of about 6 months (Fig. 1). Receivers and recorders were installed in an observation room near the experimental area (Fig. 2).

The transmitter was attached with a harness made of nylon webbing belts sewn together with colored tapes for individual recognition. Immediately after attachment of the transmitter and net fragments, the animals were released into the experimental area (Fig. 2). The experimental area, made by partitioning an inlet with nets, was about 1,400 m^2 and had a natural beach. The deepest part at high tide was about 7 m; there was a tidal range of about 1.5 m. The sea was calm throughout the year. In addition to the three experimental seals, 33 other fur seals were kept in captivity in this area. Activities of N0 were recorded continuously from 4 February to 4 March. Activities of N1 and N2, entangled in net fragments, were recorded from 28 January to 26 February. The nets were intentionally removed on 27 February and their activities without nets were recorded from 28 February to 4 March.

During the entire period, behavior and health of the experimental individuals were checked carefully at a regular time each day. Moreover, in order to compare actual movements with radio records, behavior of the three animals was observed visually several times a day for 4-5 h each time.

During the experiment, fur seals were fed with defrosted mackerel in the amount of 1-4 kg (an average of 2.44 kg) per day at 1000 and 1630 on the beach. At each feeding, food was provided first to each experimental individual, and later to the herd in general.

Weather observations were made around 1400 each day. The average air temperature during the experiment period was 10.2°C (ranging from 6.0° to 18.0°C), with average water temperature at 13.3°C (between 11.1° and 15.8°C) and average humidity at 63.1% (from 38 to 88%).

Table 1.--Information on the three fur seals used in the experiment.

| Seal | | Capture | | | Age and size at start of experiment | | |
| | | | Location | | | | |
ID	Sex	Date 1982	Latitude	Longitude	Estimated age (year)	Body length (cm)	Body weight (kg)
N0	F	9 March	36°30'N	141°16'E	6	123	29.5
N1	F	4 March	36°42'N	141°15'E	8	123	36.0
N2	F	8 March	36°26'N	141°06'E	5	120	33.0

Analysis of Activity Records

Figure 3 shows an example of the activity records of a fur seal wearing a telemetry device. Records representing the activity of the animals are called "actograms." Waves in the figure indicate changes in intensity of electric signals due to movement of the animals. When an animal with a transmitter was on land, a continuous wave form was observed (Fig. 3A); movements of the animal on land could be recognized as fluctuations of wave form on the recording paper. The period in which the wave form was fluctuating was defined as active time on land. When the transmitter-loaded animal was in the water and dived, no signal could be received because electric waves are greatly attenuated in seawater. The recording pen then moved straight along the baseline. When the animal emerged, a sharply pointed line was recorded on the paper, corresponding to the abrupt rise of electric wave intensity. Thus, actograms for the animal moving at the sea surface showed a pectinate wave form (Fig. 3B). When the seal was resting at sea, either a flat line or a baseline could be recorded. The former means that the animal was resting with her back upward, and the latter, resting with her back under water. Therefore, the fluctuating wave form indicates activity ashore, and the pectinate wave form indicates activity at sea. We measured the length of such "active" periods in each actogram and calculated the active time and resting time in a day.

RESULTS

General Behavior

During the experiment period, other fur seals did not exhibit special behavior such as avoiding or threatening the transmitter-loaded animals or approaching them with curiosity. The fur seals with transmitters were always within the herd.

Differences in the general behavior of the three fur seals were recognized by visual observation. For several days after the experiment began, N1 and N2 tried to get rid of the attached net fragments by shaking their necks. Seal N2 moved slowly and chiefly engaged in slow swimming or
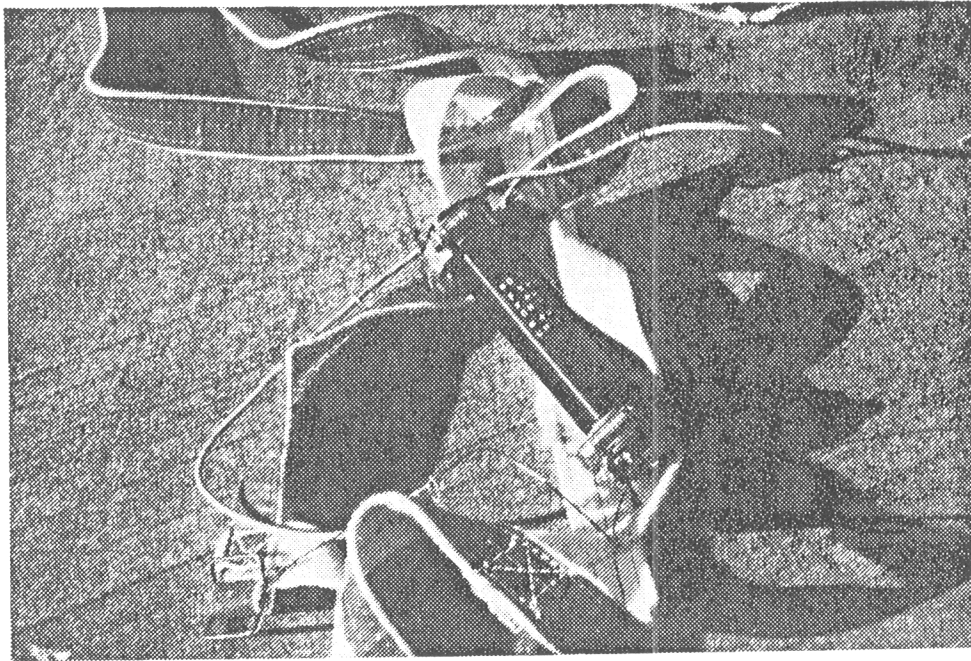
Figure 1.--A transmitter and harness.
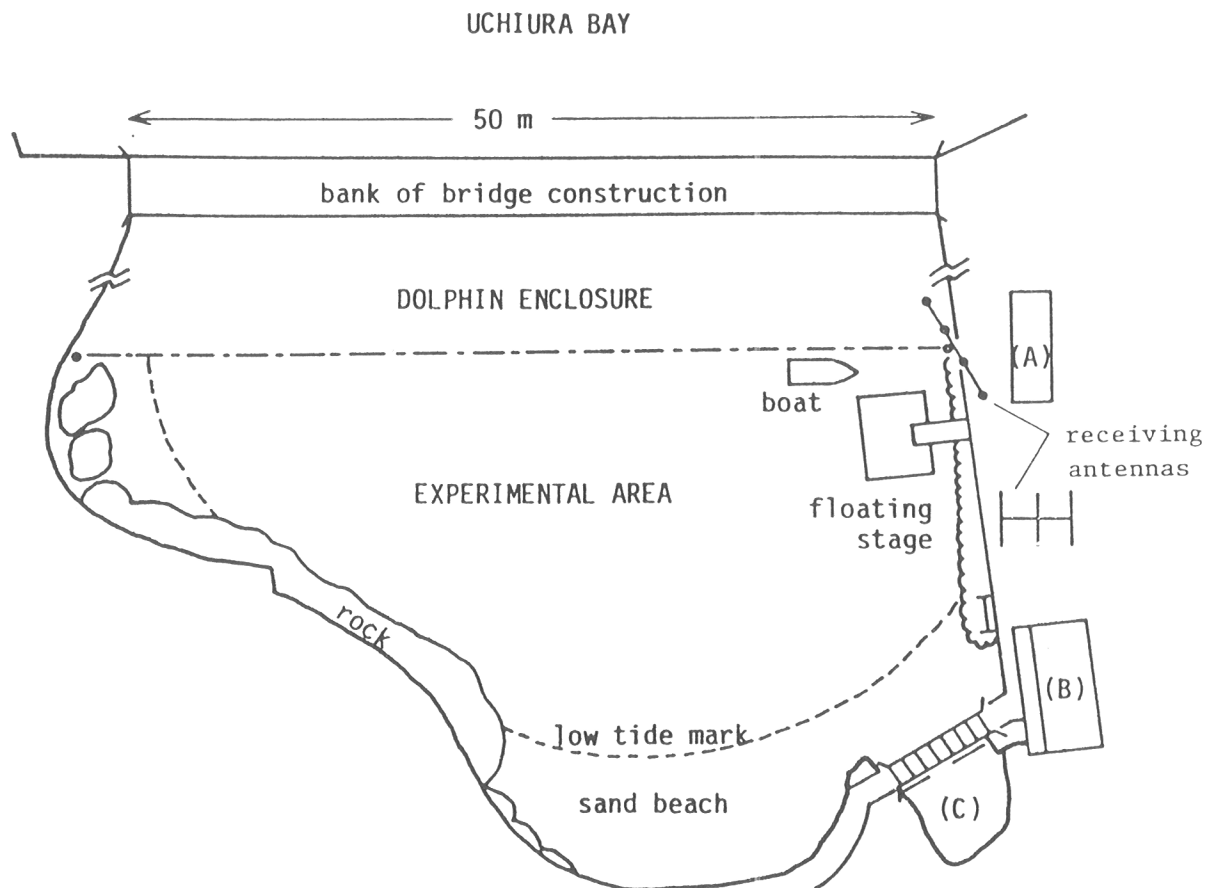
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Figure 2.--Map showing the experimental area. A. Observatory where receiving instruments were settled. B. Indoor breeding facility. C. Partitioned section where transmitters were attached.
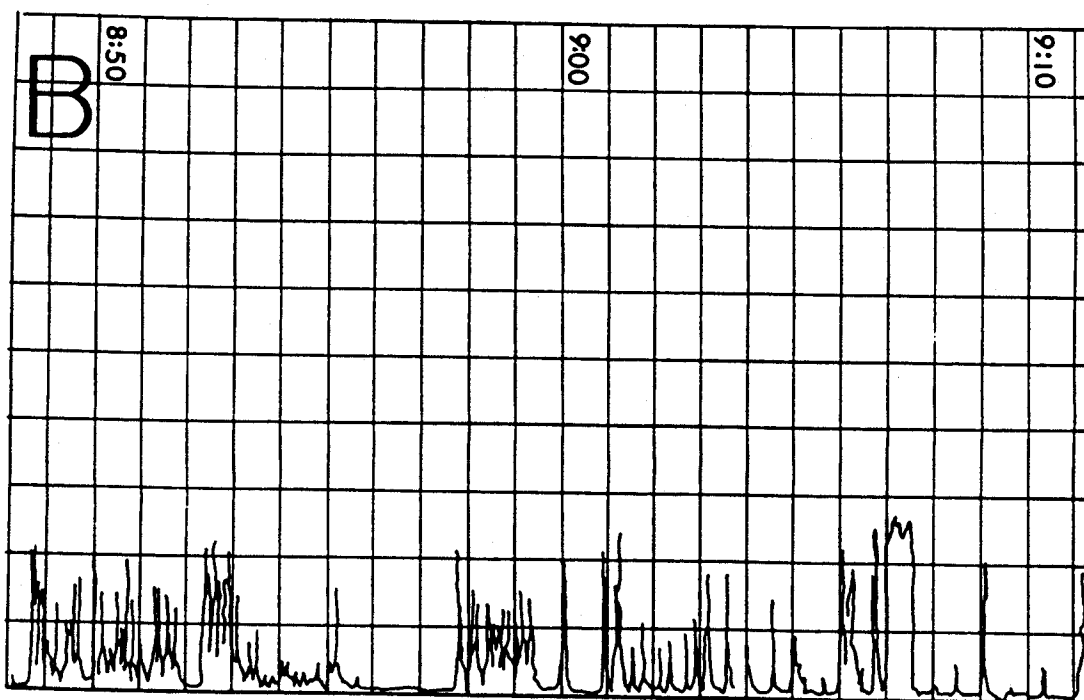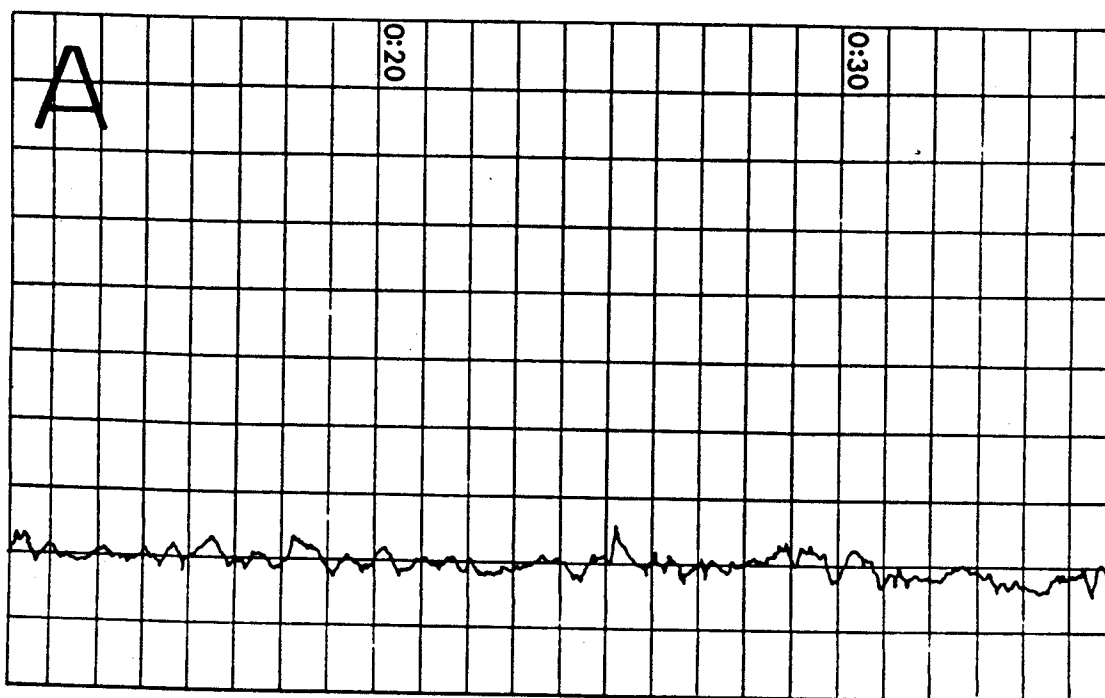
Figure 3.--Actograms, received electronic waves representing the activity of animals. A. Resting on land. B. Swimming at sea.

grooming. Dives and headstands in water, often seen in free-swimming seals, were not observed for N2. Seal N1 moved more smoothly than N2. Sometimes N2 made shallow dives or underwater headstands, but she made no extended deep dives. Seal N0's movements were very smooth and did not differ from those of individuals without transmitters.

For several days after the start of the experiment, N1 and N2 did not draw near to men even at feeding time. Later they approached the feeder as did the other seals. When food was thrown, the nonentangled individuals often caught it before the entangled ones. Seal N0's feeding activity was no different from that of nonloaded fur seals.

Activity Pattern

Active Time

Figure 4 shows variations in active time per day from 4 to 26 February. During this period, the amount of N0's active time fluctuated greatly, while fluctuations were small for N1 and N2. The average daily active time was longest for N0 (9.6 h/day), followed by N1 (4.1 h/day) and N2 (1.4 h/day), and any pair of them differed significantly (t-test, $P < 0.01$).

Table 2 shows the daily active times of N1 and N2 before and after the removal of net fragments. The average active time of N2 after net removal was 5.4 h/day, about four times longer than before net removal. The difference was statistically significant (t-test, $P < 0.01$). The average active time of N1 after net removal was 6.7 h/day, about double that of the period of net attachment, which also differed significantly (t-test, $P < 0.01$). The active time of N0 did not show a significant change between the two corresponding periods.

Daily Cycle of Activity

Figure 5 shows the average daily cycle of activity. The ratio of activity was calculated every 3 h (activity ratio) and averaged for the experiment period. For N1 and N2, the periods of entanglement and nonentanglement were treated separately. All three seals were very active in two time periods, 0900-1200 and 1500-1800, which corresponded to feeding times. Activity patterns of N1 and N2 did not change remarkably after removal of entangled nets, though the active time increased as mentioned above.

DISCUSSION

Baba and Yoshida (1988) conducted a field experiment in which they attached transmitters to two mature female fur seals, one of which was entangled in a 120-g net fragment, off St. Paul Island and compared their activities using radio telemetry. They reported that the frequency of dives longer than 1 min was less for the entangled animal. In our study, no extended dives were observed for animals loaded with nets of 1 and 2 kg. Although there were differences in research location and the amount of nets
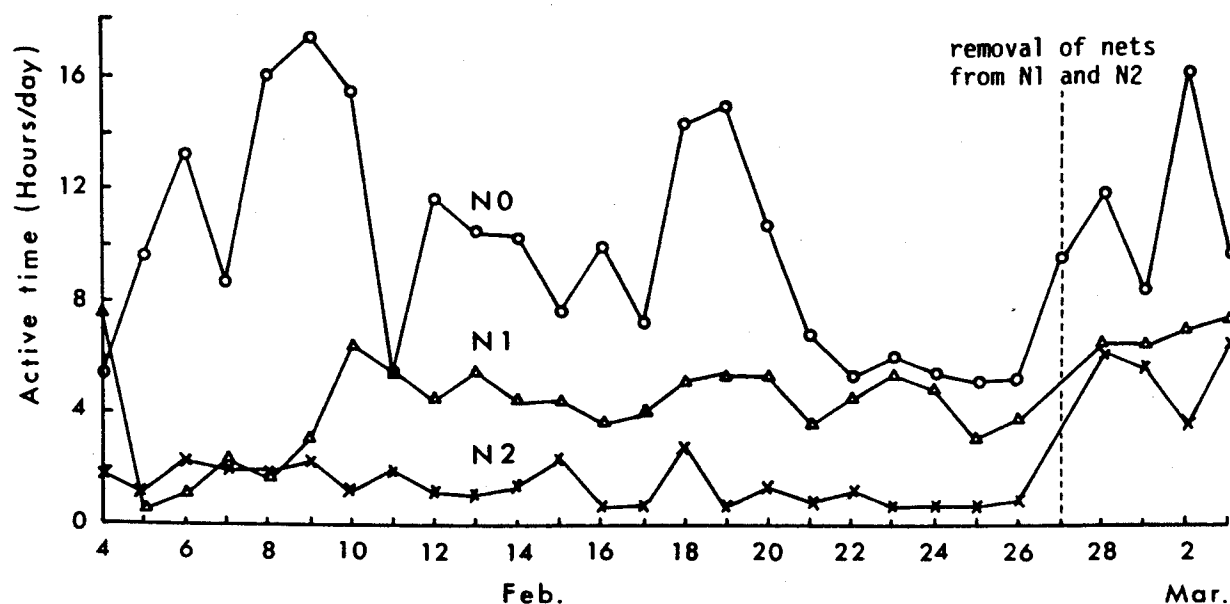
Figure 4.--Variations in daily activity of the three fur seals.

attached, their report is consistent with our study in that net entangle-
ment hindered diving activities.

Daily activity cycles were the same for entangled and nonentangled
animals. Baba and Yoshida (1988) also reported that no differences were
observed in behavior patterns of entangled and nonentangled fur seals in
the open sea. These results indicate that activity patterns of fur seals
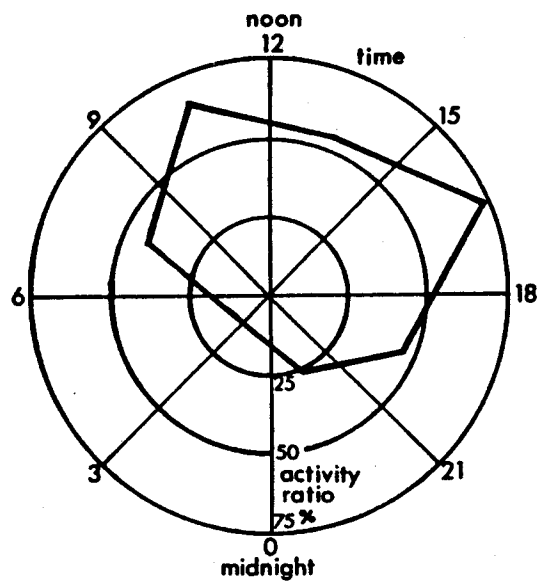may not change even if they are entangled in net fragments.

Most of the trawl nets entangling the fur seals on St. Paul Island
were <150 g in weight, although the biggest one weighed 6.75 kg (Scordino
1985). Therefore, it is also necessary to examine the effects of smaller
net fragments on activity of fur seals.

It is clear that net entanglement suppressed the activity of animals
because active time of the animals was short while entangled and increased

Table 2.--Daily active times of experimental seals with
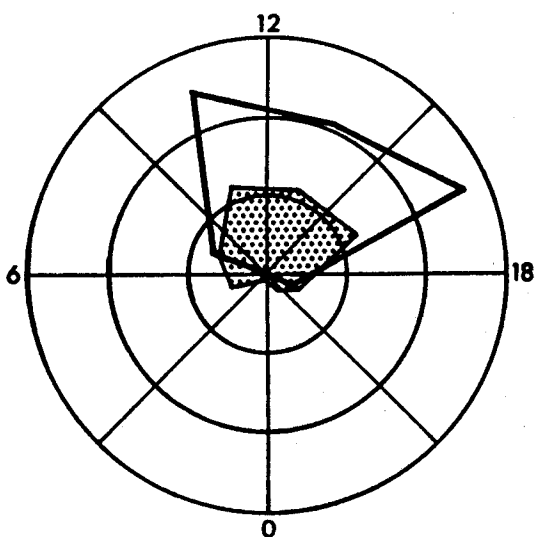and without attached nets.

		4-26 February 1985		28 February-3 March 1985		
Seal ID	Net weight (kg)	Active time per day mean (min.-max.) (h/day)	S.D.	Net weight (kg)	Active time per day mean (min.-max.) (h/day)	S.D.
N0	0	9.6 (5.0-17.4)	4.0	0	11.4 (8.2-16.1)	3.4
N1	1.0	4.1 (0.4-7.5)	1.7	0	6.7 (6.3-7.3)	0.5
N2	2.0	1.4 (0.6-2.9)	0.7	0	5.4 (3.6-6.4)	1.3

noon
12
time
15
9
6
18
25
50
activity
ratio
3
21
75%
0
midnight

N0

4 Feb – 3 Mar ; nonentangled

12

6

18

0

N1

12

6

18

0

N2

28 Jan – 26 Feb ; entangled
28 Feb – 3 Mar ; nonentangled
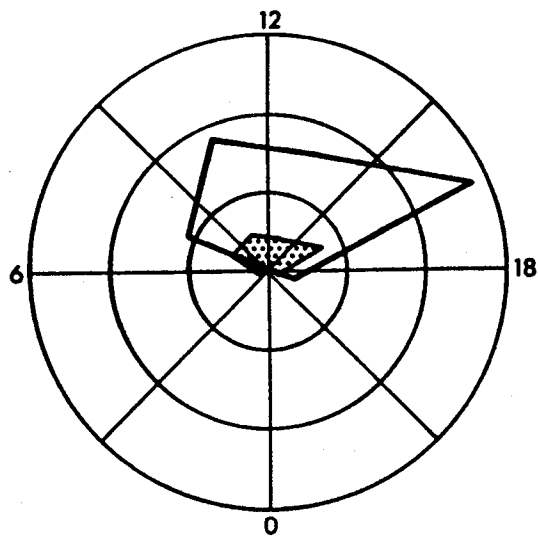
28 Jan – 26 Feb ; entangled
28 Feb – 3 Mar ; nonentangled

Figure 5.--Daily activity cycles of three fur seals for entangled (dotted area) and nonentangled (solid line) periods. Activity ratio is defined as the percentage of active time in each 3-h period.

after net removal. The suppression of activity might be due to either the physical burden of nets or an adaptation of animals to conserve energy. A future task should be to study the physiological impact of entanglement and relate it to energy consumption and survival.

ACKNOWLEDGMENTS

REFERENCES

Baba, N., and K. Yoshida.
 1988. Results of research on behavior of entangled and nonentangled fur seals by using radio-wave telemetry in areas around the Pribilof Islands, late July-early August, 1985. *In* D. L. Alverson and J. A. June (editors), Proceedings of the North Pacific Rim Fishermen's Conference on Marine Debris, Kailua-Kona, Hawaii, 13-16 October 1987, p. 165-188. Unpublished report by Natural Resources Consultants, 4055 21st Avenue W., Seattle, WA 98199.

Bengtson, J. L., C. W. Fowler, H. Kajimura, R. L. Merrick, K. Yoshida, and S. Nomura.
 1988. Fur seal entanglement studies: Juvenile males and newly-weaned pups, St. Paul Island, Alaska. *In* P. Kozloff and H. Kajimura (editors), Fur seal investigations, 1985, p. 34-57. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-146.

Feldkamp, S. D., D. P. Costa, and G. K. Dekrey.
 1987. Energetic and behavioral effects of net entanglement on juvenile northern fur seals, *Callorhinus ursinus*. Contract report to the National Marine Fisheries Service, Contract No. 85-ABC-00185, 44 p. (Available from Long Marine Laboratory, Institute of Marine Science, University of California, Santa Cruz, CA 95604.)

Fowler, C. W.
 1982. Interactions of northern fur seals and commercial fisheries. Trans. N. Am. Wildl. Nat. Resour. Conf. 47:278-292.

Scordino, J.
 1985. Studies on fur seal entanglement, 1981-84, St. Paul Island, Alaska. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 278-290. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Scordino, J., H. Kajimura, N. Baba, and A. Furuta.
 1988. Fur seal entanglement studies in 1984, St. Paul Island, Alaska. *In* P. Kozloff and H. Kajimura (editors), Fur seal investigations, 1985, p. 70-78. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-146.